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Transitioning Technology to Naval Ships

Naval Sea Systems Command
SEA 05 Technology Group

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14. ABSTRACT

Transitioning technology from the academic and industrial research environment to installation on USN ships is a complex process that intersects five domains: The S&T Community, the Resource Sponsors, the Acquisition and Engineering Community, Industry, and the Fleet. This paper presents both the current model and an alternate model for technology transition. These models reflect three drivers for inserting a new technology into a given system: filling a military capability gap, exploiting technology opportunities, and managing risk across a portfolio of systems. A discussion of how the different domains impact the processes is also included. The paper continues with a discussion of technology transition challenges, provides technology transition examples, and offers recommendations to improve the process.

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LIST OF ACRONYMS

AC	Air Conditioning or Alternating Current
AEM/S	Advanced Enclosed Mast / Sensor System
AIEPP	Advanced Integrated Electric Propulsion Plant
APMS	Advanced Performance Mast System
ASMP	Advanced Surface Machinery Programs
ASSET	Advanced Surface Ship and Submarine Evaluation Tool
ASW	Anti-Submarine Warfare
ATD	Advanced Technology Demonstration
BIW	Bath Iron Works
CCB	Configuration Control Board
CDR	Critical Design Review
CODLAG	COmbined Diesel-eLectric And Gas turbine
COEA	Cost and Operational Effectiveness Analysis
COMNAVSURFLANT	Commander, Naval Surface Force Atlantic.
D&I	Discovery and Invention
DAG	Defense Acquisition Guidebook
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DODFMR	DOD Financial Management Regulation
EMD	Engineering and Manufacturing Development
EMI	Electromagnetic Interference
EMRL	Engineering and Manufacturing Readiness Level
FMR	Field Modification Request
FNC	Future Naval Capability
FRP	Full Rate Production
FSS	Frequency Selective Surface
FSAD	Full Scale Advanced Development
FYDP	Future Years Defense Program
GAO	Government Accountability Office
GFI	Government Furnished Information
HED	Hybrid Electric Drive
HVPS	High Voltage Power System
ICA	Industrial Capabilities Assessment
IED	Integrated Electric Drive
IFTP	Integrated Fight Through Power
INP	Innovative Naval Prototype
IPA	Integrated Power Architecture
IPS	Integrated Power System
IRAD or IR&D	Independent Research and Development
IRL	Integration Readiness Level
LRIP	Low Rate Initial Production
LVPS	Low Voltage Power System
MANTECH	Manufacturing Technology
MCCDC	Marine Corps Combat Development Command

MIT	Massachusetts Institute of Technology
MMBA	Multi-Mission Multi-Beam Broad-Band Antenna
MRL	Manufacturing Readiness Level
MSA	Material Solution Analysis
NAPDD	Non-Acquisition Program Definition Document
NAVSEA	Naval Sea Systems Command
NGIPS	Next Generation Integrated Power System
NNR	National Naval Responsibility
NNSY	Norfolk Naval Shipyard
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NSWCCD	Naval Surface Warfare Center Carderock Division
ONR	Office of Naval Research
ONT	Office of Naval Technology (now part of ONR)
OPNAV	Office of the Chief of Naval Operations
PEO	Program Executive Office
PPD	Project Peculiar Document
R&D	Research and Development (entire spectrum of development)
RCS	Radar Cross Section
RSAD	Reduced Scale Advanced Development
RTT	Rapid Technology Transition
S&FAC	Ship & Force Architecture Concepts
S&T	Science and Technology (Early investigation portion of R&D)
SBIR	Small Business Innovation Research
SDD	System Development and Demonstration
SOW	Statement of Work
SPAWAR	Space and Naval Warfare Systems Command
TRL	Technology Readiness Level
TWG	Technical Working Group
VV&A	Verification, Validation and Accreditation

1. SUMMARY

Transitioning technology from the academic and industrial research environment to installation on ships of the United States Navy is a complex process that intersects five domains: The S&T Community, the Resource Sponsors in the Office of the Chief of Naval Operations (OPNAV), the Acquisition and Engineering Community, Industry, and the Fleet. This paper presents both the current model and an alternate model for technology transition from the S&T Community to the Fleet. These models reflect three drivers for inserting a new technology into a given system: filling a military capability gap, exploiting technology opportunities, and managing risk across a portfolio of systems. A discussion of how the different domains impact the processes is also included. Technology transition processes for addressing Capability Gaps and needs to replace legacy technologies are contrasted with those for addressing technologies identified as opportunities (typically for affordability).

The paper continues with a discussion of technology transition challenges:

- Transitioning Knowledge
- Transitioning Funding Responsibility
- Transitioning from Prototype to Actual System Development
- Transitioning from Actual System Development to Ship Integration
- Exploiting Technology by the Fleet
- Producing Technology Development Roadmaps
- Aligning S&T Investments with Technology Development Roadmaps
- Aligning Acquisition Strategies with Technology Development Roadmaps
- Exploiting Technology Opportunities
- Developing Product Lines vs Products
- Transitioning Tools and Methods
- Identifying Future Technology Gaps
- Funding Specifications, Standards, Rules, and Handbooks
- Improving Cost Estimation, Uncertainty Analysis, Options Analysis, and Portfolio Planning

Several technology transitions are examined using the traditional and alternate Technology Transition Models:

- Advanced Enclosed Mast / System (AEM/S) on LPD 17
- Hybrid Electric Drive (HED) on LHD 8
- Integrated Power System (IPS) on DDG 1000 and the Next Generation Integrated Power System (NGIPS)
- Set Based Design (SBD) on the Ship to Shore Connector (SSC)

The paper concludes with suggestions for improving the technology transition process

- Promote the use of Product Lines and Associated Technology Development Roadmaps
- Employ more Robust Metrics
- Improve Technology Transition Agreements
- Fully Implement Relationship Managers
- Modify the DOD Financial Management Regulation (DODFMR) to include Technology Transition Activities in BA-3.
- Modify DODFMR to split BA4 into Product Line Development and Advanced Component Development and Prototypes
- Assign OPNAV N091 as the resource sponsor for Product Line Development in addition to S&T.

2. INTRODUCTION

A naval technology transition model describes how technology is applied to a new ship design or an existing ship. A technology can manifest itself in a component design, a system architecture, a physical or software tool for creating a component or system, or a new method for requirements development, design, acquisition, fabrication, testing, operation, training, maintenance, modernization, or disposal. A new technology is typically adopted because the incumbent technology can not meet existing needs (Technology Gap), or because a new technology can fulfill existing needs in a "better" way (Technology Opportunity). An incumbent technology can be deficient for a number of reasons including: affordability, changing operational requirements, loss of industrial base to implement existing technology, scarcity of raw materials, and changing regulatory requirements (typically environmental or safety). For technology opportunities, the term "better" often refers to a lower acquisition or total ownership cost. It can also refer to other attributes such as lower operational risk, lower acquisition risk, improved safety, obsolescence avoidance, and improved robustness to future changing requirements.

The primary Merriam-Webster definition of technology is "the practical application of knowledge especially in a particular area." Technology transition in the naval context is therefore the transfer of this knowledge from those that create the knowledge to those that require the knowledge to implement a change that impacts a ship and the ship operator's (Fleet) use of the ship to fulfill naval missions. These individuals (technology transition agents) that use the knowledge are almost universally paid to do so. Therefore, the fiscal responsibility for creating, transitioning, and applying the technology is a critical aspect of the overall technology transition process. A technology transition can therefore involve both a transition of knowledge from one organization to another, as well as the transition of fiscal responsibility from one organization to another. Note that the organizations involved with the knowledge transfer may not be the same as the organizations involved in the fiscal responsibility transfer.

There are many creators of knowledge. One organization, the Office of Naval Research (ONR) through its science and technology (S&T) programs is focused on creating knowledge useful for naval applications. More precisely, ONR has the fiscal responsibility (budgeted at greater than $2B per year) for the first half of R&D, for creating knowledge in the form of technology; the actual creation of technology is typically accomplished by academia, naval laboratories, or industry. ONR, assisted by many other organizations, plays a crucial role in the creation of a naval technology portfolio by deciding which science and technology efforts to fund. However, not all technologies aiming to transition to naval ships have their origin in ONR. A number of technologies are investigated and aim to transition directly from the Defense Advanced Research Projects Agency (DARPA), industry, academia, the systems commands, or the naval laboratories.

The GAO (2006) has recognized the effective use of Relationship Managers as an Industry Best Practice for technology transition. Relationship Managers ensure that knowledge is shared across the multiple technology transition participants to ensure a common vision and alignment of activities. Within the Navy, while the term "Relationship Manager" likely does not appear in any position descriptions, a number of individuals fulfill some or most of the roles of a Relationship Manager.

The creation of a naval system, component, or process requires the integration of many technologies. The individuals that create a new technology typically do not possess all of the requisite knowledge/technology to create a product that can be integrated into a naval ship. Hence key to technology transition is the sharing or passing of knowledge to those individuals that mature the technology (create additional new knowledge) to design or build the end product for shipboard application. In many cases this knowledge is in the form of Intellectual Property such as copyrights, trademarks, patents, or trade secrets. Because in these cases technology transition involves a transaction involving something of value (Intellectual Property), technology transition can have a significant business economics aspect.

The Technology Readiness Level is a metric used by the Department of Defense and other organizations to assess emerging technologies. As currently defined in the DOD Defense Acquisition Guidebook (DAG) and shown in Table 1, there are nine technology readiness levels defined. A close examination of the definitions of the various Technology Readiness Levels indicate that this metric measures the degree to which the knowledge associated with the technology is integrated with other technologies to create a useful product. TRLs in general focus on components and systems employed by the end-user. Technology associated with tools and methods employed in the design and production of the end product are not as easily measured using the currently defined TRLs.

Figure 1 shows the general progression of Technology Transition from early basic research through fielding in operational systems. The maturation of technology by ONR through TRL 5 or 6 is defined as the Science and Technology (S&T) portion of Research and Development (R&D) using R&D BA1 through BA3 funding (OPNAV 1993). Systems Commands (such as NAVSEA) and their affiliated PEOs typically fund the maturation of technology from TRL 5 or 6 to TRL 7 using BA4 funding. (Note that the definitions for BA3 and BA4 overlap between TRL 5 and 6) For ship technology, much of the BA-4 funding in the past 15 years has been tied to specific ship acquisition programs, with little funding dedicated to maturing technology for cross ship application. In many cases, technology developed by the S&T Community piles up on the "shelf" waiting for BA-4 funding to mature the technology to the degree acceptable by the Acquisition Programs. This lack of BA-4 cross-platform technology funding, organizational responsibility, and program management authority is often depicted as the R&D "Valley of Death." (Figure 2). The maturation of technology from TRL 7 to TRL 8 and TRL 9 is typically done by ship program managers using BA-4, BA-5, SCN or OPN funding.

Not all technology transitions enter the Navy's R&D process as part of the U.S. Navy S&T portfolio. As will be shown in the LHD 8 Hybrid Electric Drive example, some significant technologies skip S&T and are directly incorporated from industry into a ship design to achieve a TRL 8.

One shortcoming of using TRLs as a metric is that they are lagging indicators; TRLs report achievements to date and do not necessarily measure the likelihood of transition success in the future. The Engineering and Manufacturing Readiness Level (EMRL) (Table 2) and more recently the Manufacturing Readiness Level (MRL) (Table 3) provide additional metrics in terms of the end goal of producing a product and are more characteristic of a leading indicator. In practice, these metrics are all useful in evaluating an end product technology.

The TRL, EMRL, and MRL are not particularly well suited to measuring the maturity of technologies associated with design, design tools, construction, or other processes. While many design tools are software based, they are generally not acquisition programs and governed more by Verification, Validation, and Accreditation (VV&A) requirements than traditional acquisition milestones. VV&A is not addressed by the traditional TRL or for software TRLs as defined by DOD (2009). The TRL, EMRL, and MRL are also not good metrics for other aspects of technology transition such as Intellectual Property rights and the status of specifications and standards. Figure 3 shows a notional technology maturity scorecard used by Boeing that includes these additional metrics.

Other proposed maturity assessment metrics include the Integration Readiness level (IRL) and the Systems Readiness Level (SRL). The IRL is a qualitative measure of "maturity, compatibility, and readiness of interfaces between various technologies," The SRL is a quantitative measure consisting of a "normalized matrix of pair-wise comparisons of TRLs and IRLs of a system." (Azizian et al. 2009) The Air Force Research Laboratory has developed a Microsoft Excel based tool, the "AFRL Transition Readiness Level Calculator" that automates the assessment of Technology Readiness Level, Manufacturing Readiness Level, and Programmatic Readiness Level."

None of the established metrics are entirely suitable for evaluating non-material technologies such as design methods and analysis tools. Research in this area would likely be very fruitful.

While the Navy is interested in transitioning technology to a ship program, the Navy is also interested in adopting a technology as a standard way of doing business. Doerry (2006) lists completion of the following activities as elements of "institutionalizing" a technology for broad use across the fleet:

- Demonstrate the technology early
- Incorporate the basic technology into production units
- Establish a common architecture and interfaces
- Establish a common design process
- Incorporate the architecture and design processes into design tools
- Codify the practice in Government or industry specifications, standards and guides.
- Teach the architecture and design process as part of a typical engineering school curriculum.[1]

The status of completing these activities is also an important metric for technology transition.

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[1] For classified technologies, an alternate method for passing on the technology to the next generation of engineers is required.

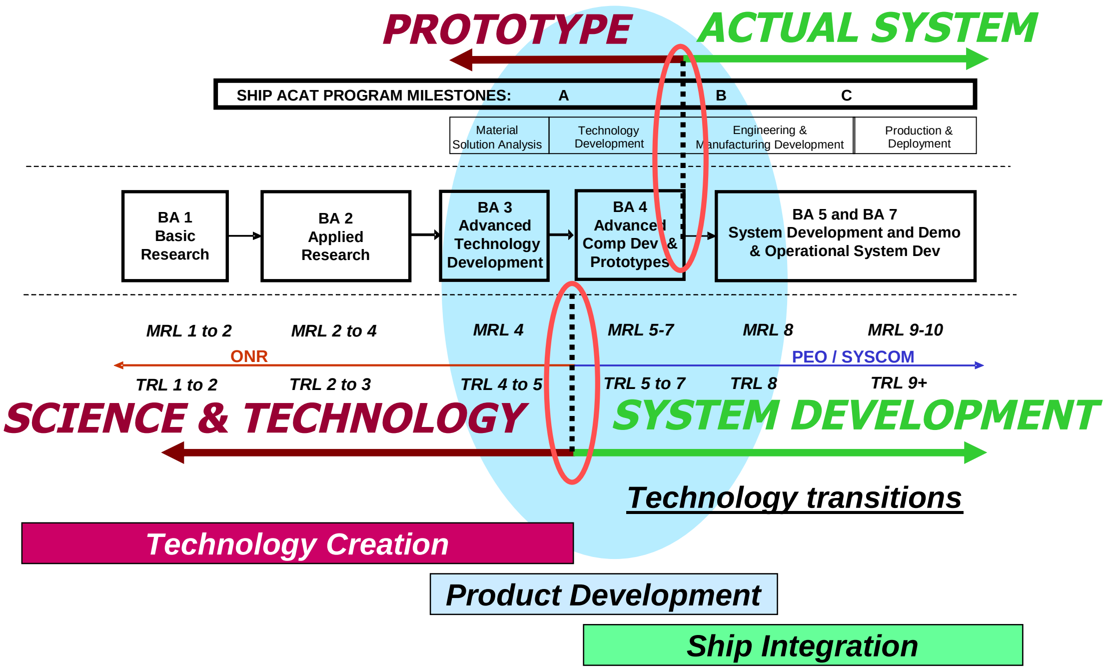

Figure 1: Technology Transition Timeline

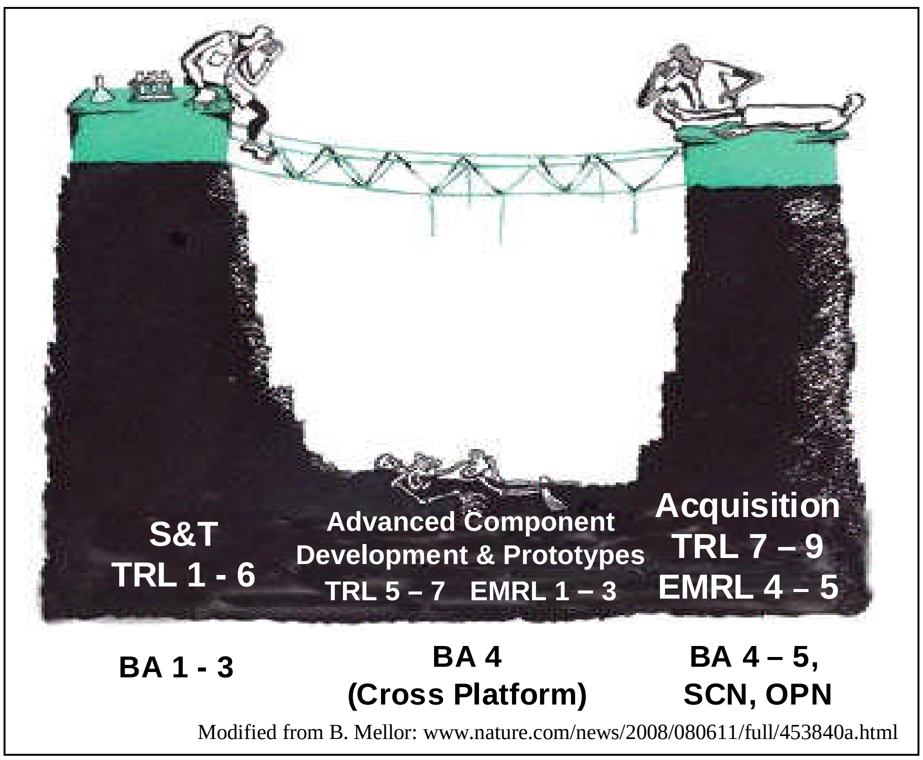

Figure 2: R&D Valley of Death

Technology Readiness Level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Table 1: Technology Readiness Levels (DAG 2010)

Engineering and Manufacturing Readiness Levels

1. System, component, or item validation in laboratory environment or initial relevant engineering application or breadboard, brass board development

Significant system engineering or design changes. System engineering requirements not validated. Physical and functional interfaces not defined. High program risk. Materials tested in laboratory environment. Machines and tooling demonstrated in laboratory environment. Manufacturing processes and procedures in development in laboratory environment. Quality and reliability levels and key characteristics not yet identified or established. Includes requirements of TRL 4 and TRL 5 as a minimum.

2. System or components in prototype demonstration beyond breadboard, brass board development.

Many systems engineering and design changes. Systems engineering requirements validated and defined. Physical and functional interfaces not fully defined. High program risk. Risk assessments initiated. Materials initially demonstrated in production. Manufacturing processes and procedures initially demonstrated. Machines and tooling require major investment. Inspection and test equipment developed and tested in manufacturing environment. Quality and reliability levels and key characteristics initially identified. Includes requirements of TRL 6 as a minimum.

3. System, component, or item in advanced development. Ready for low-rate initial production.

Few systems engineering or design changes. Prototypes at or near planned system engineering for required performance levels for operational system. Physical and functional interfaces clearly defined. Initial risk assessments completed. Moderate program risk. Materials in production and readily available. Manufacturing processes and procedures well understood and ready for low-rate initial production. Moderate investment in machines or tooling required. Machines and tooling demonstrated in production environment. Inspection and test equipment demonstrated in production environment. Quality and reliability levels and key characteristics identified, but not fully capable or in control. Includes requirements of TRL 7 as a minimum.

4. Similar system, component, or item previously produced or in production. System, component, or item in low-rate initial production. Ready for full-rate production.

Minimal systems engineering or design changes. All systems engineering requirements met. Minimal physical and functional interface changes. Initial risk assessments complete. Low program risk. Materials available. Manufacturing processes and procedures established and controlled in production to 3-sigma level. Minimal investment required in machines or tooling. Machines, tooling, and inspection and test equipment deliver 3-sigma quality in production. All key characteristics controlled to 3-sigma level in production. Includes requirements of TRL 8 and 9 as a minimum.

5. Identical system, component, or item previously produced or in production. System, component, or item in full-rate production.

No systems engineering or design changes. Identical system, component, or item in production or previously produced that met all engineering requirement for performance, quality, and reliability. Low program risk. Materials, manufacturing processes and procedures, inspection and test equipment, quality and reliability, and key characteristics controlled in production to 6-sigma level. Proven affordable product.

Source: OUSD(ATL), 2003.

Table 2: Engineering and Manufacturing Readiness Levels

MRL	Definition	Description	Phase
1	Basic Manufacturing Implications Identified	Lowest level of manufacturing readiness. The focus is addressing manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (budget activity BA 1) begins in the form of studies.	Pre Materiel Solution Analysis
2	Manufacturing Concepts Identified	Characterized by describing the application of new manufacturing concepts. Applied research (budget activity BA-2) translates basic research into solutions for broadly defined military needs. Typically this level of readiness in the S&T environment includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging.	Pre Materiel Solution Analysis
3	Manufacturing Proof of Concept Developed	Validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in the S&T funding categories of Applied Research and Advanced Development (budget activity BA-3). Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.	Pre Materiel Solution Analysis
4	Capability to produce the technology in a laboratory environment.	S&T Programs typically in the budget activity BA-2 and BA-3 categories and acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.	Materiel Solution Analysis(MSA)leading to a Milestone A decision.
5	Capability to produce prototype components in a production relevant environment.	Level of maturity typical of the mid-point (*or earlier for ship programs*) in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.	*Early* Technology Development (TD) Phase.
6	Capability to produce a prototype system or subsystem in a production relevant environment.	Associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. *(For ships, this level should be achieved for components prior to the completion of Preliminary Design and before the start of Contract Design)* Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes completion of S&T development and acceptance into a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design of critical components has been completed and producibility assessments of key technologies are complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. A cost analysis has been performed to assess projected manufacturing cost versus target cost objectives and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been completed. Long-lead and key supply chain elements have been identified.	Technology Development (TD) phase leading to a Milestone B decision. *(Achieved prior to completion of Preliminary Design and the start of Contract Design for ship programs)*
7	Capability to produce systems, subsystems or components in a production representative environment.	Typical for the mid-point of the Engineering and Manufacturing Development (EMD) Phase leading to the Post-CDR Assessment. (*For ships this level is achieved for components during late Technology Development phase leading to a Milestone B decision).* Technologies should be on a path to achieve TRL 7. System detailed design activity is underway. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments are underway. The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets. Unit cost reduction efforts have been prioritized and are	Engineering & Manufacturing Development(EMD) leading to Post CDR Assessment *(Late Technology Development phase leading to a Milestone B decision for ship programs)*

		underway. The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place. Production tooling and test equipment design and development have been initiated.	
8	Pilot line capability demonstrated. Ready to begin low rate production.	Readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is essentially complete and sufficiently stable to enter low rate production. All materials are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. The engineering cost model is driven by detailed design and has been validated with actual data. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established and stable.	Engineering & Manufacturing Development (EMD) leading to a Milestone C decision.
9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.	At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.	Production & Deployment leading to a Full Rate Production (FRP) decision.
10	Full Rate Production demonstrated and lean production practices in place.	Highest level of production readiness. Technologies should have matured to TRL 9. Level of manufacturing normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing.	Full Rate Production/ Sustainment

Note: Interpretation for ship programs added by author and indicated by italics

Table 3: Manufacturing Readiness Level (DOD 2010)

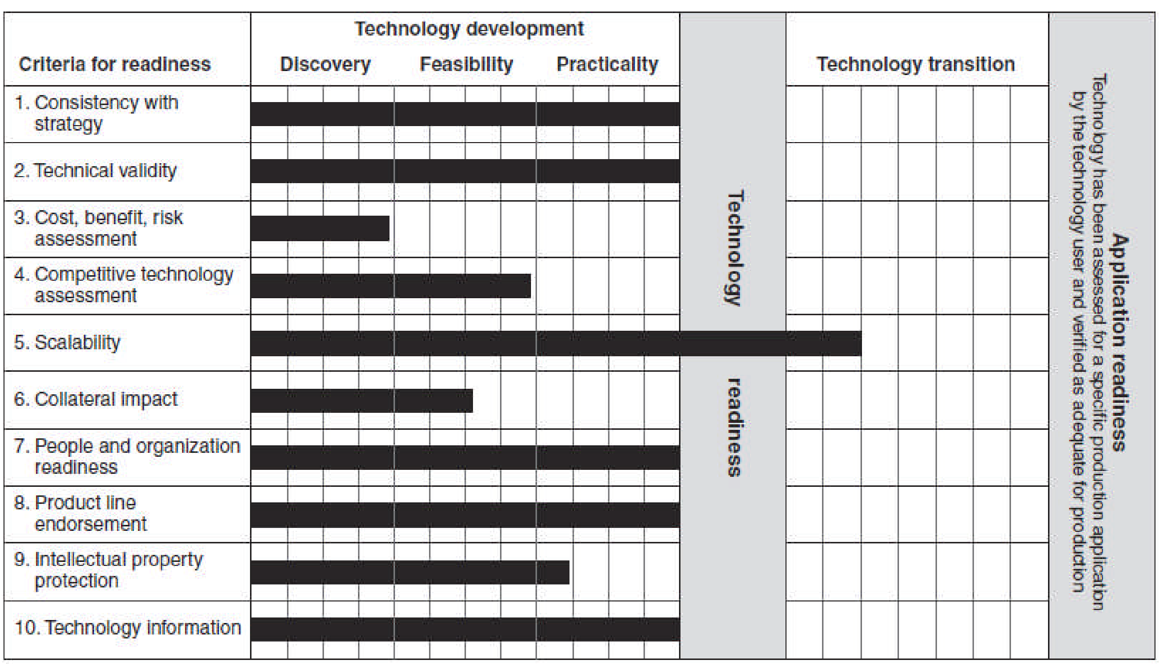

Figure 3: Notional Boeing Technical Maturity Scorecard (GAO 2006)

3. TECHNOLOGY TRANSITION PARTICIPANTS

Figure 4 shows a simplified model of the interactions among the five principal participants in Technology Transition: Science and Technology Community, Resource Sponsors, Acquisition and Engineering Community, Industry, and the fleet.

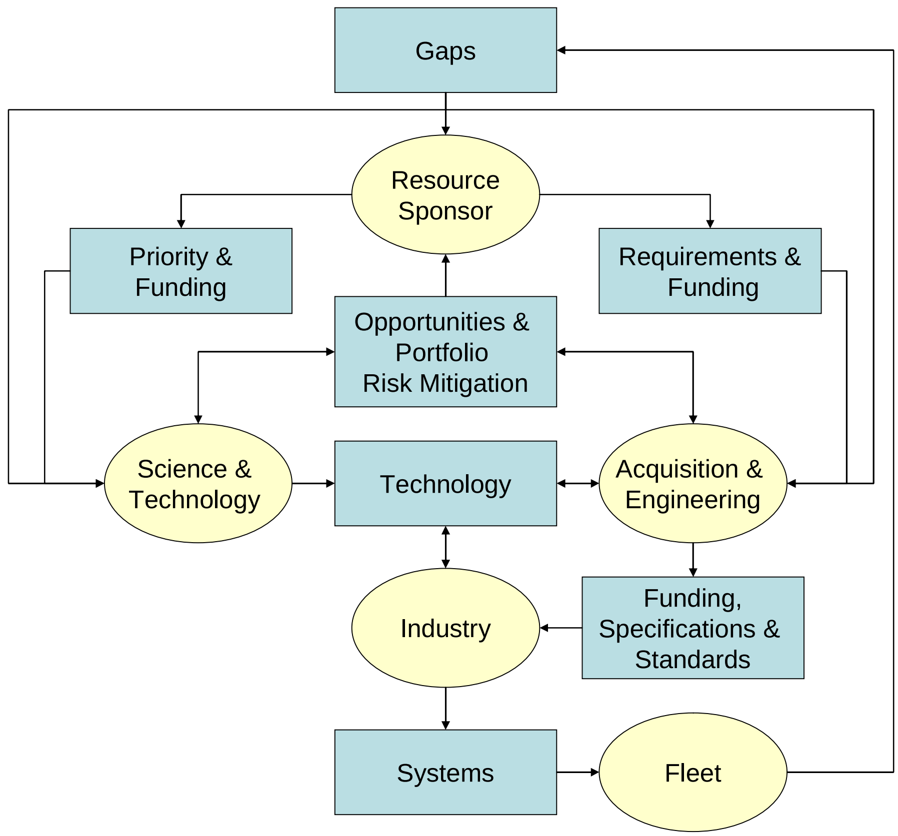

Figure 4: Simplified High Level Interaction of Technology Transition Participants

3.1 Science and Technology Community

The Science and Technology Community consists of the Government, industrial, and academic scientists, engineers, and managers who develop and understand technology for future applications. The Science and Technology Community not only develops new technology, but also identifies to the Resource Sponsors and Acquisition & Engineering Community technical opportunities and options for technology portfolio risk management. The Resource Sponsors provide funding and priority for S&T initiatives. Gaps identified by the Fleet are used to focus S&T efforts. The Acquisition & Engineering also provides feedback with respect to technical opportunities and portfolio risk management for specific technical areas. Within the Navy, the Office of Naval Research, the Navy Research Laboratory, the Warfare Centers, and elements of the Systems Commands comprise the majority of the Navy's government portion of the Science and Technology Community.

3.2 Resource Sponsors

Within the Navy, the Resource Sponsors are generally part of the Office of the Chief of Naval Operations (OPNAV). The Resource Sponsors represent the end user (Fleet) in developing requirements for acquisition programs. The fleet identifies and prioritizes gaps for the resource sponsor to fund technology development programs. The S&T Community and the Acquisition and Engineering Community identify to the Resource Sponsors Technology opportunities and portfolio risk management opportunities. The Resource Sponsors also allocate funding to the various programs, thereby prioritizing at a high level technology and acquisition initiatives.

The Resource Sponsors do not comprise a monolithic organization. Table 1 lists the resource sponsors typically engaged with technology development for ships. Of particular note, the S&T resource sponsor (OPNAV N091 – currently dual-hatted as the Chief of Naval Research) is different from the platform sponsors for BA-4 and later efforts. Thus the transition from BA-3 to BA-4 generally requires organizational transitions for both the Resource Sponsors and the S&T / Acquisition and Engineering Community.

Furthermore, technologies that impact multiple sponsors requires a considerable amount of coordination that can be very challenging at times – each resource sponsor expects the other resource sponsors to "foot the bill" for common technologies. This is particularly true for surface ship technology that in the BA-4 and later efforts, can involve N42 (combat logistics force ships), N85 (amphibious warfare ships), N86 (surface combatants), and N88 (aircraft carriers).

Science & Technology	OPNAV N091
Strategic Mobility and Combat Logistics	OPNAV N42
Expeditionary Warfare	OPNAV N85
Surface Warfare	OPNAV N86
Submarine Warfare	OPNAV N87
Air Warfare	OPNAV N88
Special Programs	OPNAV N89

Table 4: Resource Sponsor Examples

3.3 Acquisition and Engineering Community

The acquisition and Engineering Community translates requirements and funding from the Resource Sponsors into funding, specifications and standards for industry to develop systems for the end-user. They transition technology from the Science and Technology Community to those designing, constructing, using, and maintaining naval systems. Within the Navy, the Acquisition and Engineering Community resides primarily in the Program Executive Offices, Systems

Commands, and Warfare Centers. The Acquisition and Engineering Community generally communicates system descriptions to industry via Statements of Work (SOW), standards and specifications.

The program offices within the PEOs are generally focused on a narrow range of ship applications – typically aligned with a resource sponsor. Coordinating technology development that spans the ranges of multiple program offices has proven challenging. In the past these technologies were developed by the Systems Commands (such as NAVSEA). During the past 15 years however, the System Command programs conducting this cross-platform technology development have been cut dramatically. BA-4 funding has been largely allocated to program offices to support specific ship acquisitions. One consequence of this loss of cross-platform technology development has been the explosion of unique equipment and systems that have been introduced to the fleet with recent ship acquisitions. Recent investments in commonality efforts are attempting to reverse this trend.

3.4 Industry

Most products are produced by Industry. Consequently, technology transition often consists of transitioning knowledge from the Science and Technology Community to Industry. In other cases Industry has developed technology itself and must transition it to the Acquisition and Engineering Community to ensure the SOWs, standards and specifications incorporate the new technology.

3.5 Fleet

For most systems, the Fleet is the end user. The fleet communicates current gaps and projected future gaps in capability to the Resource Sponsor, Science and Technology Community, and the Acquisition and Engineering Community. The Fleet also acts as the resource sponsor, transition agent, and execution agent for a limited number of high impact, high technology turnover, modest cost R&D / acquisition efforts.

ONR Science Advisors serve as a Fleet Commander's senior liaison with science and technology organizations in government, academia and industry. They communicate needs and requirements back to the Office of Naval Research and the Science and Technology Community to help shape S&T investments. Science Advisors serve as Relationship Managers to enable rapid technology insertions, long-term investment leverage and surge capability in support of high-priority fleet issues.

4. TECHNOLOGY TRANSITION MODEL

4.1 Traditional Technology Transition Paradigm

As shown in Figure 5, the traditional view of technology transition shows technology moving sequentially along the budget activities. Knowledge is transitioned at the boundaries between budget activities. Work generally should not start in a budget activity unless previous work is judged complete by having attained a specified Technology Readiness Level. The traditional view emphasizes identifying and finding solutions for specific technology gaps identified by the warfighter or acquisition community.

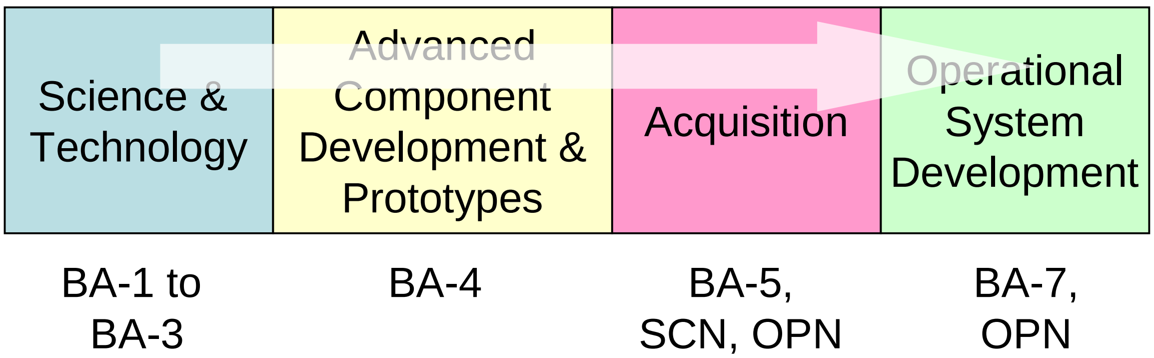

Figure 5: Traditional Serial View of Technology Transition

4.1.1 Science and Technology (BA-1, BA-2, BA-3)

Science and Technology encompasses Basic Research (BA-1), Applied Research (BA-2), and Advanced Technology Development (BA-3). As described in the Naval S&T Strategic Plan (ONR 2009) the Navy's Science and Technology Vision is to "sponsor scientific research and technology to:

- Pursue revolutionary capabilities for Naval forces of the future
- Mature and transition S&T advances to improve naval capabilities
- Respond to current critical needs
- Maintain broad technology investments both to hedge against uncertainty and to anticipate and counter potential technology surprise."

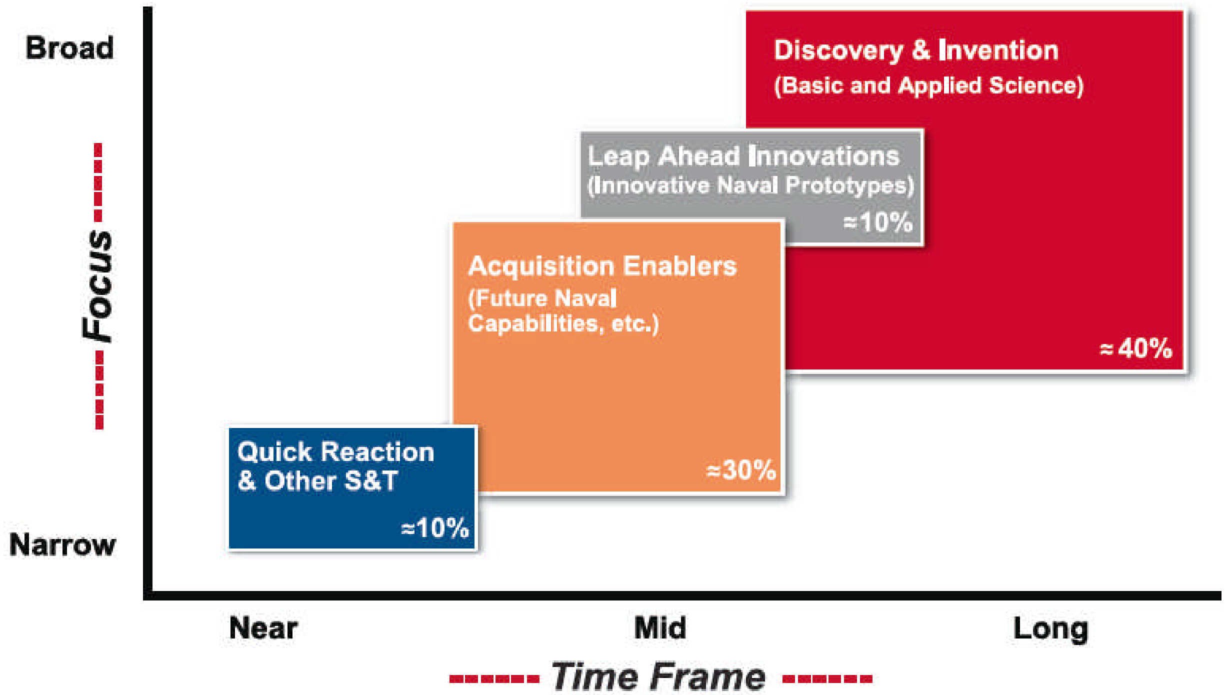

Figure 6: ONR S&T Portfolio Breakdown

As shown in Figure 6, the ONR S&T Portfolio is broken down into 4 categories described in the ONR S&T Strategic Plan:

- Discovery and Invention (D&I) consists of Basic Research (Budget Activity (BA-1) and early Applied Research (BA-2), and is the seed corn for future naval technologies and systems. The D&I portfolio, by design has a broad focus, and programs are selected based on potential naval relevance and technology opportunity. D&I investments leverage other service, governmental, department, industry, international and general research community investments. The D&I portfolio supports sustained funding of the four National Naval Responsibilities (NNR): Ocean Acoustics, Underwater Weaponry, Naval Engineering and Undersea Medicine.
- Leap Ahead Innovations include Innovative Naval Prototypes (INPs) and Swampworks, and are technology investments that are potentially "game changing" or "disruptive" in nature. INPs achieve a level of technology suitable for transition (to Advanced Component Development and Prototypes) in four to eight years. Swampworks efforts are smaller in scope than INPs and are intended to produce results in one to three years. This category is where higher risk is typically accepted in an effort to produce higher payoff for the warfighters.
- Acquisition Enablers center on the Future Naval Capabilities (FNCs). These work to mature technology into requirements-driven, transition oriented products in the late stages of Applied Research and Advanced Technology Development (BA-3). FNCs provide enabling capabilities to fill gaps in OPNAV and MCCDC requirements analyses identified in the Navy and Marine Corps strategies and Naval Power 21. In addition to FNCs, ONR also uses Small Business Innovation Research (SBIR), Manufacturing

Technology (MANTECH) programs and Rapid Technology Transition (RTT) to foster naval acquisition programs' success.

- Quick Reaction S&T includes ONR Tech Solutions and Navy/Marine Corps Experimentation. These are quick-reaction projects responsive to the immediate needs identified by the fleet, operating forces, or Naval leadership.

In DoD Financial Management Regulation (DODFMR) (DOD 2008) the definition of BA-3 includes:

"Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of Science and Technology (S&T) and into the acquisition process within the future years defense program (FYDP). Upon successful completion of projects that have military utility, the technology should be available for transition."

Note that this definition only requires that technology be available for transition, but does not actually include transition activities.

4.1.2 Advanced Component Development and Prototypes (BA-4)

This stage is defined by the DODFMR:

"Efforts necessary to evaluate integrated technologies, representative modes or prototype systems in a high fidelity and realistic operating environment are funded in this budget activity. The ACD&P phase includes system specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems and may involve risk reduction initiatives. Program elements in this category involve efforts prior to Milestone B and are referred to as advanced component development activities and include technology demonstrations. Completion of Technology Readiness Levels 6 and 7 should be achieved for major programs. Program control is exercised at the program and project level. A logical progression of program phases and development and/or production funding must be evident in the FYDP."

BA-4 programs are managed by the Systems Commands and the Program Executive Offices (PEO). For ship technology, much of the BA-4 funding in the past 15 years has been tied to specific ship acquisition programs, managed by the Program Offices in the PEOs.

4.1.3 Acquisition (BA-5, SCN, OPN)

The acquisition phase consists of BA-5 System Development and Demonstration and the procurement of the end product.

The System Development and Demonstration stage is defined by the DODFMR:

"SDD programs have passed Milestone B approval and are conducting engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. This budget activity is characterized by major line item projects and program control is exercised by review of individual programs and projects. Prototype performance is near or at planned operational system levels. Characteristics of this budget activity involve mature system

development, integration and demonstration to support Milestone C decisions, and conducting live fire test and evaluation and initial operational test and evaluation of production representative articles. A logical progression of program phases and development and production funding must be evident in the FYDP consistent with the Department's full funding policy."

For ships, procurement is generally funded via the SCN (Shipbuilding and Conversion, Navy) or OPN (Other Procurement, Navy) accounts.

4.1.4 Operational System Development (BA-7)

This stage is defined by the DODFMR:

"This budget activity includes development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year. All items are major line item projects that appear as RDT&E Costs of Weapon System Elements in other programs. Program control is exercised by review of individual projects. Programs in this category involve systems that have received Milestone C approval. A logical progression of program phases and development and production funding must be evident in the FYDP, consistent with the Department's full funding policy."

4.2 Alternate Technology Transition Paradigm

Drawbacks of the traditional Technology Transition Paradigm include its serial view of technology development activity, and its presumption that technology requirements are well known relatively early in the process. The serial nature of the traditional process results in long times required to move technology from the laboratory to the fleet. The presumption that technology requirements can be predicted to any degree of certainty a decade before being incorporated into a ship is highly questionable. Sustaining support for S&T efforts requires close coordination with the transition programs. Unfortunately, much of the S&T must be accomplished before there is any definition of the acquisition programs the technology will transition to.

Instead of a series model, an alternate Technology Transition Paradigm is shown in Figure 7. This model views technology transition as transitioning knowledge among 4 overlapping activities. The activities focused on knowledge creation continuously transition knowledge to activities that define and maintain a Product Line from which application specific products can be derived.

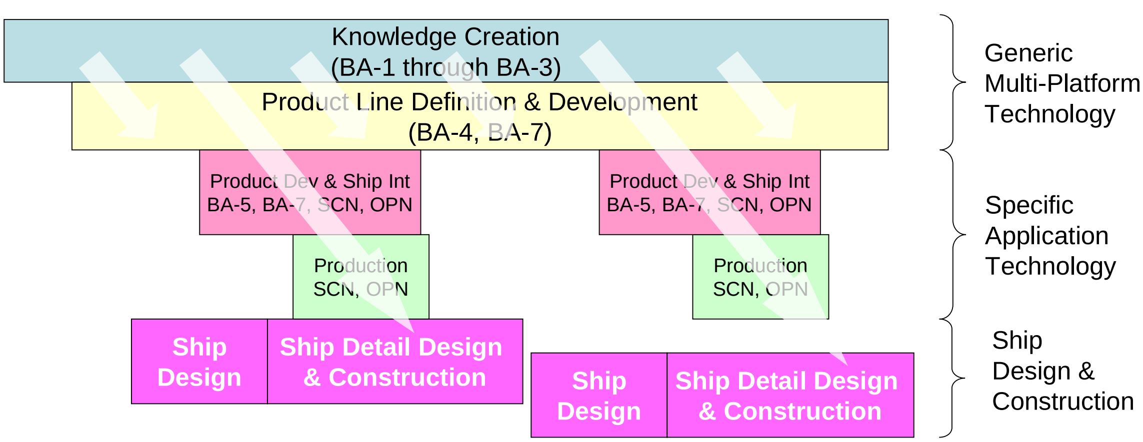

Figure 7: Alternate Technology Transition Paradigm

In this model, the Product Line serves as a transition for technology from the Knowledge Creation activities. When a definite gap, opportunity, or risk mitigation effort is realized, an application specific product is developed and produced. In-service upgrades are treated in the same manner. Commonality across ship types is promoted because of the common product line heritage of all products. The technology encompassed in the Product Line is continually refreshed from the Knowledge Creation activities.

4.2.1 Knowledge Creation (BA-1, BA-2, BA-3)

The focus of this activity is creating useful knowledge and transitioning it to a product line and eventually to a product. Knowledge Creation spans technology that is approaching TRL 1 through TRL 5. Transitioning of this technology involves both knowledge and fiscal responsibility for further development. The knowledge must transition to those accomplishing the Product Line Definition and Development and eventually those accomplishing the Product Development and Ship Integration. Dedicated Navy funding is typically accomplished through programs employing BA1 through BA3. In some cases, knowledge is created and transitioned by engineers and scientists that do not normally work in traditional Science and Technology programs. These engineers may normally work in one of the other technology transition areas and create the knowledge through inspiration, through experience, or through necessity to make a product work.

Industry may fund Knowledge Creation through their Internal Research and Development (IRAD) funds.

The principal means of communicating knowledge from the Knowledge Creation activities to the Product Line Definition and Development activities are through personal interaction and written documents. These products of the Knowledge Creation activity are typically technical reports, technical journal papers, presentations and patents. The results of experiments and prototype testing are included in these products. Ideally, the technical reports would include proposed changes to existing standards, specifications, and handbooks, or proposed draft language to support the creation of new standards, specifications, and handbooks.

4.2.2 Product Line Definition and Development (BA-4, BA-7)

The focus of this activity is creating the capability to rapidly design and produce a product that meets customer needs. Prototypes are designed, built and tested to validate the capability. The primary purpose of the prototype is not to anticipate the specific requirements of an application, but to validate design tools, design methods, manufacturing methods, and the ability to integrate the product into a system. The Product Line should be fully supported with Standards, Specifications, and Handbooks to facilitate the design of multiple systems and procurement of multiple products within the product line. This activity achieves an initial operational capability when the producer is capable of delivering on time, a successful product for integration into a ship with an affordable fixed price contract.

For simple products that are a fit-form-function replacement for existing components, this activity is simplified to establishing the capability to competitively manufacture the new components and validate that the new components meet the fit-form-function requirements.

For new processes and tools, this activity includes incorporation of the new technology into standards and handbooks, into work instructions and standard practices, and into Statements of Work and Specifications where applicable. The workforce is trained and the process or tool used in a

prototype or low risk application. The technology is transitioned when the new process or tool and its associated workforce is ready for a real application.

Product Line Definition and Development can begin when supporting technologies are typically at least a TRL level 3. While early on the technology is matured through the Knowledge Creation activity, the technology transition to Product Line Definition and Development is governed by a Technology Transition Agreement. This activity matures technology received at TRL 5 from the Knowledge Creation activity and transitions technology when supporting technologies are typically at least a TRL level 7. The Product Line Definition and Development efforts also inform the S&T community of technical areas that would benefit from increased S&T investment. Generally, most of the technologies selected for incorporation into a product line will be a TRL level 9. Usually a less mature technology will be used only if that technology differentiates the product line and provide measurable improvement over competing product lines. In this way, these BA-4 efforts and the S&T efforts work simultaneously and interactively to advance the product line.

This activity encompasses work to accomplish EMRL 1, 2, and 3. Work to attain an EMRL of 1 should occur while the Knowledge Creation Activity is maturing technology to a TRL of 5. An EMRL of 3 (with the associated TRL level 7) should be achieved before transitioning a product to a ship program.

The development and maintenance of a Product Line should be supported by a Technology Development Roadmap that projects the planned evolution of a product line as supporting technologies are developed. This document is an important vehicle for the S&T Community to describe potential for new technologies and the Product Line developers to describe the usefulness and potential application of new technologies within the Product Line. The Technology Development Roadmaps are also a means for communicating with the Ship Integration teams with respect to the requirements and opportunities for technology insertion for specific ship programs. These Technology Development Roadmaps provide the context for the development of specific Technology Transition Agreements for particular technologies.

Ideally, to minimize systems integration risk, a product line is developed before the specific needs of a given ship program are determined. The product line should be capable of meeting the needs of multiple ship classes and enable commonality across the fleet. An EMRL of 3 implies a TRL of 7 for being able to deliver a product that meets the specific needs of ship. For new construction, ship requirements are initially developed during Preliminary Design following Milestone A and finalized during contract design prior to Milestone B. An EMRL of 3 should therefore be achieved by the end of the ship’s Preliminary Design. This generally requires the product line development to start well before the ship’s Milestone A. The product line must anticipate the potential needs of multiple ships before the Analysis of Alternatives of some or all of them have been completed. For this reason, the product line should generally span a range of potential requirements; specific requirements will not be known until later stages of ship design and may not be exactly identical across multiple ship classes.

4.2.3 Product Development and Ship Integration (BA-5, BA-7, SCN, OPN)

The focus of this activity is producing a product to specific requirements based on the product line previously defined. This activity achieves EMRL 4 and the associated TRL of 8 or 9. Typically this stage would include all the design work, production, and testing for the first units installed on a

ship. This stage also includes efforts required to modernize components already installed shipboard to take advantage of new technology since the ship was built, or to reflect new requirements.

4.2.4 Production (SCN, OPN)

The focus of this activity is full rate production and achieving EMRL 5. Ideally, there would be no systems engineering or design changes, although obsolescence, regulatory changes, diminishing sources, cost reduction efforts, etc. may require design modifications. Manufacturing methods are well established as indicated by identical system, component, or item in production or previously produced that met all engineering requirement for performance, quality, and reliability. Low program risk is achieved. Materials, manufacturing processes and procedures, inspection and test equipment, quality and reliability, and key characteristics controlled in production to 6-sigma level. The product is proven affordable.

5. TECHNOLOGY TRANSITION CHALLENGES

5.1 Transitioning Knowledge

In the current Technology Transition Paradigm, technology is created in the S&T Community using BA-1 through BA-3 funding. BA-4 funding is typically provided via a ship acquisition program following the ship's Milestone A when the ship needs are known. Typically this leaves only 1 to 2 years to mature a technology to TRL 7 by early Contract Design for the ship, and 3 to 4 years for the components/systems in their final form to be ready for shipboard installation and testing prior to attaining TRL 8. This very short timeline, with little margin for error, requires an effective transition of knowledge from the S&T Community to the Engineering and Acquisition Community and Industry. The current paradigm has this technology transition occur as a specific event when fiscal responsibility changes from BA-3 to BA-4. Since BA-3 funding only includes maturing a technology to be ready for transition, concerted transition activity does not take place until funded by BA-4 programs. Since the BA-4 programs are strongly motivated to achieve TRL 7 within a few years, technologies that are difficult to understand or integrate into existing design processes are assessed a higher risk and are more likely to be excluded from a BA-4 program.

Another barrier to transitioning knowledge can be intellectual property rights. If the developers of the knowledge retain the rights to the knowledge, but are not capable of or willing to produce a military product, technology transition can fail. A recent example is that after funding a shipyard to develop submarine concept design algorithms, the Navy was denied permission to incorporate those algorithms into its Advanced Surface Ship and Submarine Evaluation Tool (ASSET) due to not having sufficient Intellectual Property rights language in the contract. The Navy is now starting over using Navy engineers to develop algorithms for incorporation into ASSET.

5.2 Transitioning Funding Responsibility

In the current Technology Transition Paradigm funding responsibility for a technology typically shifts from ONR to an acquisition program between BA-3 and BA-4. Acquisition programs typically have only a narrow window to accept new technologies; for ships this is during the roughly one year preliminary design. Hence timing the completion of S&T to coincide when it must be mature enough for consideration in an acquisition program is very difficult. This is compounded by acquisition program funding and schedule instability. If the timing is off, a technology transition can fail due to either the team with the knowledge disbanding due to a lack of funding, or the technology development abandoned because it will not mature in time for the acquisition program.

5.3 Coordinating Funding Across Resource Sponsors

The transition from BA-3 to BA-4 also involves a transition in Resource Sponsors. Multiple Resource Sponsors can provide BA-4 funding. For technologies that span multiple ship platform types, particularly those for surface ships, it can be difficult to coordinate multiple resource sponsors to fully fund a technology development effort. Each Resource Sponsor would rather that other Resource Sponsors pay for the development.

5.4 Transitioning from Prototype to Actual System Development

A prototype developed by the S&T community generally does not have all features necessary for integration into a warship. Requirements such as shock, Electromagnetic Interference (EMI), and

other environmental considerations are not incorporated into the prototype. Furthermore, the prototype is many times designed and constructed by an organization that is not experienced in producing a fully militarized product. Hence either the developers of the new technology must gain the additional knowledge and technology to develop a militarized product, or an existing manufacturer of militarized equipment must learn the new technology and how to incorporate it into a militarized product. Consequently, considerable work and integration risk can remain following the S&T prototype demonstration.

5.5 Transitioning from Actual System Development to Ship Integration

Technology transition is not complete when a militarized product that meets requirements is produced. This product must still be integrated into a ship. Hence knowledge must also be transitioned to the Navy engineers writing ship specifications, engineering changes, and ship change documents, planning yard engineers, and shipyard engineers. For many technologies, effective integration of new technology is greatly facilitated by modification to existing specifications, standards, design data sheets, and class society rules. Unfortunately, technology development programs often do not fund updating these documents, and there is currently insufficient funding to maintain the existing specifications, standards, and design data sheets.

In many ship acquisition programs, this knowledge is captured in Government Furnished Information (GFI), Project Peculiar Documents (PPDs) or directly in the ship specifications. Unfortunately, while developing a PPD or specific ship specification language is less expensive than developing a cross platform standard, they only apply to the specific project. These documents must be revisited and continually modified for application to other ship types -- at greater total cost to the Navy and with a greater risk of error.

Existing metrics for technology readiness do not typically capture the status of the ship integration efforts.

5.6 Exploiting the Technology By the Fleet

The linkage between the new capabilities installed in a ship and the training a ship's crew receives is not always the strongest. Without proper training, the crew may not have the knowledge to properly use the new capability. In some cases, the initial crew is trained by the component or system manufacturer, but because the training material is not incorporated into the Navy's training curriculum, the follow on crews are less able to operate and maintain the equipment and systems. These issues are not typically captured in technology transition metrics.

5.7 Producing Technology Development Roadmaps

Technology Development Roadmaps are useful documents for focusing the activities of the five technology transition participants. Technology Development Roadmaps present one or more architectures for a given discipline and highlight the technology needs to support those architectures. Technology Development Roadmaps are generally written to providing common architectures to multiple applications. Of particular note, Technology Development Roadmaps are not an execution plan; they highlight what needs to be done, but not how or who needs to accomplish it. Technology Development Roadmaps should be produced in collaboration among the five technology transition participants. A good Roadmap will result in the alignment of multiple S&T and R&D efforts for a common purpose without requiring tight coordination among the efforts. A written roadmap is

useful for indicating the technology direction desired, and due to not including resource aspects, it is long-lived enough (several years) to be worth developing and distributing.

One of the challenges in developing a Technology Development Roadmap is that while its success depends on the five technology participants collaborating, the participants are generally resourced independently. Ensuring all the participants have the right resources at the right time to produce a collaborative Technology Development Roadmap can be challenging.

5.8 Aligning S&T investments with Technology Development Roadmaps

In deciding which S&T efforts to invest in, the current practice does not explicitly measure the alignment of the effort with applicable Technology Development Roadmaps. Ideally, a good portion of BA2 and much of BA3 efforts should follow the Technology Development Roadmaps to ensure the technologies are aligned with a broader goal. On the other hand, not all S&T need be, or should be, aligned; technology that is disruptive and potentially an improvement over the current vision should always be explored, but not at tremendous expense to advancing the collaborative vision documented in the Technology Development Roadmap.

While the technology development strategy documented in the Technology Development Roadmaps should be stable over a period of years, investment planning is very dynamic. Investment plans are continually updated to reflect the numerous changes that occur, annually, monthly, and weekly.

5.9 Aligning acquisitions strategies with Technology Development Roadmaps

Current practice also does not promote aligning acquisition strategies with Technology Development Roadmaps. In many acquisition strategies, the selection of technologies is left to the contractor. The contractor is not required to consider the architectures or technologies developed in accordance with the Technology Development Roadmap. This can result in the contractor developing new approaches, even inferior ones, to the well researched and developed technologies in the roadmap. The contractor may do so to improve its own economic position at the expense of the Navy.

5.10 Exploiting Technology Opportunities

Current practice ranks S&T initiatives that fulfill identified technology gaps over other technologies. Consequently, justifying S&T efforts to exploit opportunities is more difficult. This is compounded by the lack of metrics for discriminating among multiple technology opportunities. Opportunities are often based on affordability, and costs are difficult to accurately estimate during the S&T phases. S&T investments generally concentrate on the technical viability of a concept rather than the fiscal viability.

Some opportunities develop especially quickly, so some reserve funding in a cross-platform BA-4 technology development program should be allotted annually to exploit emerging opportunities. Defending the budget for unspecified opportunities can be challenging.

5.11 Product vs. Product Line / Capability Development

Current practice champions the development of products that can directly transition to acquisition programs. The downfall of this approach is that is that it is nearly impossible to predict

the specific requirements of an acquisition program during the S&T phases. Follow on acquisition programs many times are forced to repeat much of the development work to produce a product meeting the program's needs. The alternate transition model instead has S&T transition to a product line that covers a wide range of possible acquisition program requirements. Much product line development work can be accomplished prior to an acquisition program levying specific product requirements. The goal of a product line is to be capable of rapidly and affordably producing a product meeting customer needs with minimal risk.

5.12 Transitioning Tools and Methods

Current practice has difficulty evaluating S&T that develops tools and methods instead of hardware and software employed in the final system. One reason is that TRLs and EMRLs are not well suited for measuring the transition readiness of tool and method technologies. Another reason is that tools and methods are likely not to be identified as gaps by the warfighter – hence these initiatives may be ranked lower. Furthermore, while S&T tools and methods initiatives will often produce academic code or draft procedures, the initiatives do not always include the experiments necessary for creating the data needed for Validation and Verification. There is also little BA 4 funding to translate these academic tools and methods into production tools and production methods.

5.13 Identifying Future Technology Gaps

Generally, the ability to predict the future to any degree of accuracy is limited to less than a decade. The S&T horizon however, extends beyond this time frame. As a consequence, understanding alternate potential futures and the likelihood of future Technology Gaps is a challenging problem that requires special expertise. It is not clear that the current practice of querying the fleet for gaps will result in an effective identification of the key technologies that should be worked on today to ensure success in the future.

5.14 Funding Specifications, Standards, Rules, and Handbooks

Technology is fundamentally knowledge. The S&T community captures knowledge in the form of Technical Reports and Professional Journal Articles. The Acquisition and Engineering Community captures knowledge in Specifications, Standards, Rules and Handbooks. Incorporating the knowledge from the S&T community into the Acquisition and Engineering Community requires the latter to fully understand the new technology and how it impacts the latter's products. This can require a lot of effort because the S&T products are generally not written to facilitate their incorporation into specifications, standards, rules and handbooks. Unfortunately, the translation of the knowledge from the S&T community products into the Acquisition and Engineering Community products is greatly underfunded. Hence good S&T may not successfully transition.

6. TECHNOLOGY TRANSITION EXAMPLES

6.1 Advanced Enclosed Mast / Sensor System on LPD 17

Figure 8: U.S.S. San Antonio (LPD 17)

The Advanced Enclosed Mast / Sensor System (AEM/S) on U.S.S. San Antonio (LPD 17) (Figure 8) is a good example of a technology that originated in ONR and successfully transitioned to an acquisition program. The capture and transition of knowledge was an integral part of the early AEM/S development. AEM/S also is a good example of early parallel S&T and R&D efforts in a product line approach that facilitated effective technology transition as well as an effective approach to managing the interaction of the technology transition participants. The AEM/S also represents a technology that has not been fully institutionalized. The history of the AEM/S development up through 1999 is well documented by Carlisle and Ellsworth (2000). Meloling (2001) provides a good description of the AEM/S System (Figure 9):

> "The Advanced Enclosed Mast/Sensor (AEM/S) System uses advanced composites to produce a mast structure that encloses the existing legacy antenna systems of the ship. This enclosure consists of a composite sandwich structure that supports all internal decks, antennas, and ballistic cable trunks. Embedded within the composite sandwich are frequency selective surface (FSS) layers that filter electromagnetic waves. This filtering allows transmission and reception at desired frequencies while rejecting threat radar signals. Once these electromagnetic characteristics are designed into the composite sandwich, the mast structure can be shaped to reduce the radar cross section (RCS).
>
> The AEM/S technology has many advantages. AEM/S provides affordable signature control of legacy antenna systems. Developing and fielding new antenna systems is a long and costly process. The AEM/S System provides a near-term means of reducing the RCS of ships. Many of the newer antenna systems under development plan to use phased array antennas. The faceted nature of the AEM/S structure provides the necessary flat surfaces for mounting these future systems. The

performance of the enclosed shipboard antennas is improved over conventional metallic masts because there is less blockage of the antenna. Maintenance of the enclosed antennas is reduced because the antennas are not exposed to adverse weather, wind loading, salt water, or stack gases. Less maintenance directly reduces costs over the entire service life of the ship."

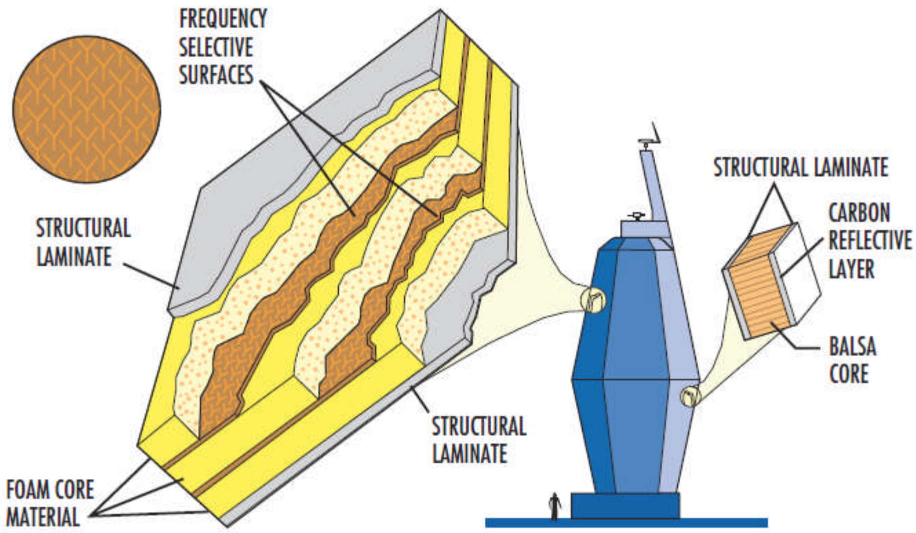

Figure 9: Advanced Enclosed Mast / Sensor System

The AEM/S System had its origin in 6.2 Science and Technology programs[2] in the areas of materials, structures, signatures, and electromagnetics. In 1990, the Search Radar Branch at the Naval Research Laboratory (NRL) created a draft report suggesting four approaches to mast design that took advantage of composites. The second of these four approaches encased radars in a composite structure with internal platforms. This approach lowered Radar Cross Section (RCS), reduced weight, eliminated mast blockages, protected the radars from the environment, and offered some protection from blast fragments and overpressure. This draft report also listed a number of issues that had to be addressed to make the concept viable.

In 1991 or 1992 a Technical Working Group (TWG) was formed to coordinate S&T efforts in support of developing a proposal for an Advanced Technical Development (ATD) program. This TWG was comprised of members from the Office of Naval Technology (ONT – later merged with ONR), NAVSEA, NSWC Carderock, NSWC Dahlgren, NCCOSC San Diego, and NRL. In 1992 and 1993, the 6.2 efforts were funded via the Advanced Performance Mast System (APMS) program under the ONR Management of Jim Gagorik. Programmatic management of the funds was divided between John Eadie of NAVSEA 06K and Carl Pohler of NAVSEA 05R. Jeff Benson from NSWC Carderock became the technical leader of APMS. Even at these early stages, the Resource Sponsor,

[2] Much of the AEM/S early development predated the 3 December 1993 change in budget categories from the 6.1 through 6.6 designation to the BA 1 through BA 7 designations. The old 6.1, 6.2, and 6.3a designations closely relate to the respective current BA 1, BA 2, and BA 3 designations. While technically obsolete, the 6.X designation is still used in many documents with the X referring to the current Budget Activities.

Science and Technology Community and elements of the Acquisition and Engineering Community were working together in a collaborative environment.

In 1993, plans for the 6.3 funded AEM/S Advanced Technology Demonstration (ATD) program began to take shape. In July 1993, discussions commenced with Ingalls Shipbuilding to add industry to the team. During this time LCDR John Spencer (NAVSEA 05R) and Jeff Benson became effective Relationship Managers by communicating the advantages and opportunities of the AEM/S ATD concept to the Resource Sponsors and Acquisition and Engineering Community, and by relaying the concerns of these two communities back to the S&T Community. During 1994 the organizational lines of communication shown in Figure 10 developed. Note the integration of all the technology transition participants except for the fleet.

In anticipation of starting the ATD in October 1994, the TWG established goals to generate a conceptual baseline by December 1993 and a preliminary design of the ATD by September 1994. In developing these baselines, a product line approach was employed. The TWG did not know whether the ATD would transition to a back fit on existing destroyers, or a forward fit on unspecified future ships. More importantly, the development of the product line also highlighted technical issues that then could be addressed by the associated 6.2 research.

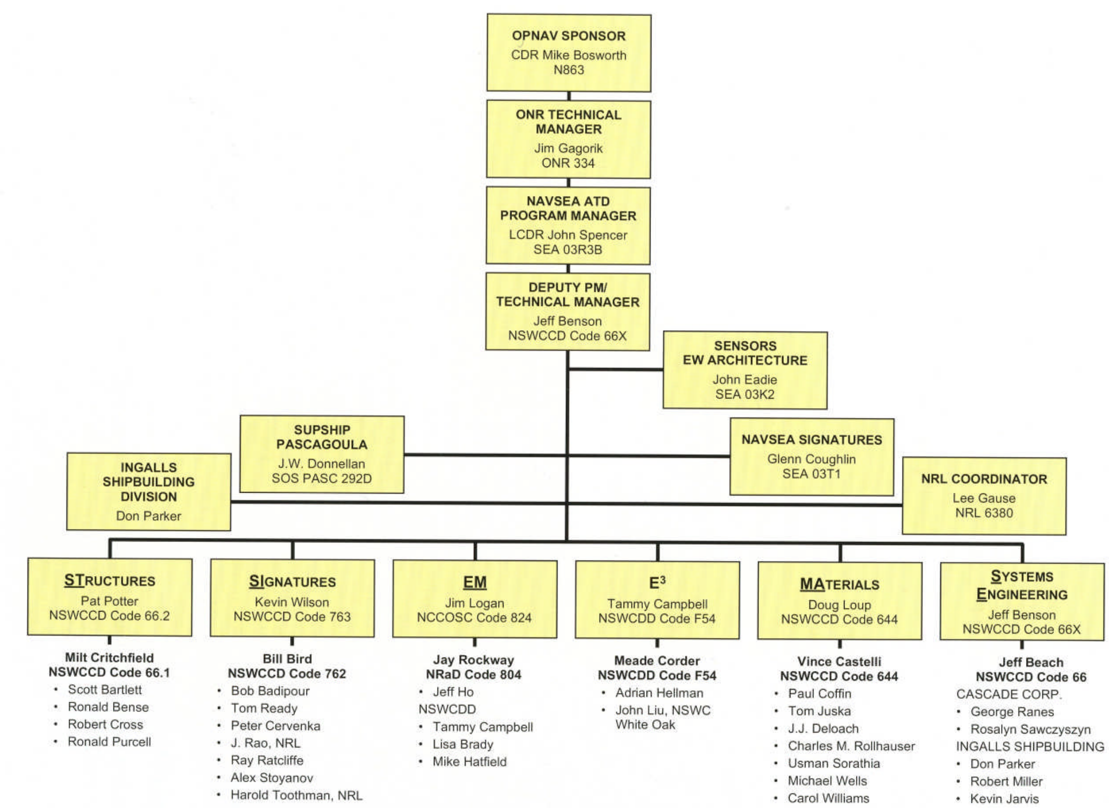

Figure 10: AEM/S Organizational Structure in July 1994

Another important accomplishment in 1994 was the issuance of a Non-Acquisition Program Definition Document (NAPDD) that established the AEM/S System as a program that would mature

technology, but not deliver a final production product to the fleet. The NAPDD included a simple "Transition Plan" through the inclusion of a paragraph that read:

> "6. Transition Plan. Planned transition is phased as follows: (1) Completion of at-sea validation of performance predictions under PE63513, S1712 in FY98; and (2) Ship concept pre-milestone 0 studies to optimize tradeoffs, payoffs versus cost, under PE63563, S2196 beginning in FY99. N86 has budgeted for and will support transition of the technologies demonstrated in this ATD to the 21st century surface combatant, LHX and other future ships, subject to changes in future budgets and shipbuilding plans. The composite materials and electromagnetic technologies will also enable the integration of next generation antennas (e.g. multi-mission multi-beam broad-band antennas (MMBA), solid-state shared aperture, etc.) to be transitioned to surface ships as planned under FY94 PE0303109, X0731."

One of the important technology transitions that occurred was between Seemans Composites, the developers of the composite manufacturing method, and Ingalls Shipbuilding, the shipyard tasked with manufacturing the ATD mast. The ATD was fortunate in that these two companies worked well together.

During 1994, work on "Technology Batons" commenced to capture and document how specific technical decisions were made, and how the different alternatives considered where evaluated. These documents were intended to be a primary method of transitioning the developed technology to a future production system. The Technology Baton concept was championed by LCDR John Spencer. Unfortunately, in September 1995, following the transfer of LCDR John Spencer to another assignment earlier that year, further development of Technology Batons was stopped to reduce cost. Instead, an effort was made to capture all relevant working documentation into a repository.

In November 1994, COMNAVSURFLANT designated *U.S.S. Conolly* (DD 979) as the ship to host the AEM/S ATD mast. COMNAVSURFLANT reserved the right to halt the installation if doing so would constitute "an unacceptable risk." In July 1995, COMNAVSURFLANT changed the host ship to *U.S.S. Radford* (DD 968) because of the acceleration of *Conolly*'s Restricted Availability from August 1997 to October 1996. By early 1996, the crew of *Radford* was participating in design and progress reviews. At this point all the major Technology Transition Participants were actively engaged in the AEM/S ATD.

In early 1995, discussions began with the LPD 17 Design Team for incorporating AEM/S. These discussions and design application issues would continue through 1996. On October 23, 1996, CAPT Maurice Gauthier, LPD Ship Acquisition Program Manager, agrees to install the AEM/S on LPD 17, contingent on the success of the ATD testing. An LPD 17 Integrated Process Team (IPT), sponsored by ONR, NAVSEA and SPAWAR was formed to design and integrate a next-generation AEM/S system for LPD 17. This team would also transition the technology to the LPD 17 industry alliance that was designing and building LPD 17.

Figure 11: U.S.S. Arthur W. Radford (DD 968) with AEM/S

During 1995 and 1996, elements of the AEM/S system were fabricated and tested. Many technical issues were identified and solved. One notable change to the design was replacing almost 6 feet of the bottom of the mast with an aluminum deckhouse pedestal (plinth) to reduce the cost of integrating the mast to the ship (Figure 12). The original design would have required significant rerouting of cables, pipes, and other interferences from the overhead of the deck below the mast. Construction of the mast completed in 1997 and the mast barged from Ingalls in Pascagoula, MS, to Norfolk Naval Shipyard (NNSY) in Virginia. On, May 17, 1997, eleven days after arrival in NNSY, a "Mast Stepping" ceremony is held to celebrate installation on *Radford*.

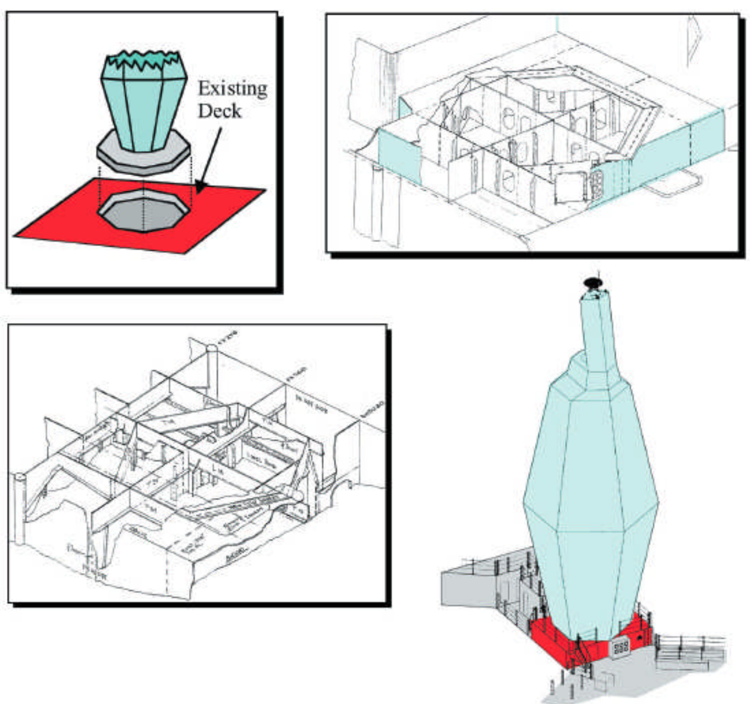

Figure 12: Original and Modified (Plinth) methods for integrating AEM/S to *U.S.S. Radford (DD 968)*

To facilitate technology transition from Ingalls, the builder of the mast, to NNSY, the integrator of the mast to the ship, a *Manufacturing Play Book* was created. Similarly, to facilitate technology transition to the *Radford* crew, an *Owner's Manual* was created to detail installed equipment, handling and usage restrictions, man-aloft procedures, Concept of Operations modifications, damage control equipment and doctrine, and inspection & maintenance.

Testing of the AEM/S system on *Radford* was conducted through 1999. The outstanding performance of the AEM/S System led to a meeting on May 11, 1998, subsequently confirmed by a naval message on May 29, 1998 where COMNAVSURFLANT elected to leave the AEM/S onboard *Radford* for the rest of her service life.

The LPD 17 IPT, composed largely of the same individuals that designed the ATD mast plus LPD 17 ship designers, continued to meet through out 1997 and 1998 to develop the concept for the LPD 17 AEM/S system. This new application differed significantly from the ATD. As described by Carlisle and Ellsworth:

> "There were several major differences between the destroyer mast mounting and the LPD mast mounting. First of all, in the ATD on board *Radford*, only the aft stick mast had been replaced with an enclosed mast system. On the LPD, both forward and aft masts would be replaced, in order not just to demonstrate the principle of reduced radar signature, but to achieve actual reduction of the signature."
>
> "One consideration was the fact that since the enclosed mast would go on board the LPDs before, not after, they were completed, the mast could be built on a higher deck structure, not requiring the complex shape of the *Radford* mast, but a simpler, elongated pyramidal shape.
>
> Since the mast was to be original equipment that would be expected to last out the forty-year life of the ship, several other considerations would have to be included in the design. Panels in the mast would have to be removable so that radar and other equipment inside could be taken out and replaced. Such considerations meant that it would not be all possible to simply build another *Radford* mast and put it on the LPD 17-class ships. Rather it would require many modifications of the earlier mast design for each of the two masts for the new ships. The effort was likely to be more extensive than that expended in building the original AEM/S System."

On June 22, 1998, the LPD 17 Configuration Control Board (CCB) approved preparing a Field Modification Request (FMR) to install fore and aft AEM/S System masts on LPD 17. Bath Iron Works (BIW) commences to prepare the FMR in July 1998. The FMR (FMR 120) was approved by the Program Manager, CAPT William (Bill) Luebke on February 9, 1999. CAPT Luebke (Luebke 2010) stated that he was confident that the AEM/S system would work (he had great confidence in the onsite NAVSEA 05 Engineering team and the Government – Contractor IPT), but was concerned with cost and schedule. In particular, neither shipyard involved in the construction of the LPD 17 class (Bath Iron Works and Avondale) could be convinced to contract for the construction of the LPD 17 mast with Ingalls Shipbuilding, the builder of the *Radford* mast. Both Bath Iron Works and Avondale viewed gaining the technology to build composite structures as important to being competitive for future contracts. Consequently, the lessons learned with producing the *Radford* mast had to be relearned (at significant cost to the Navy) by a new production crew. In deciding whether to approve the FMR, CAPT Luebke was swayed by the potential for total ownership cost reduction

as well as the RCS performance. Strong advocates for the AEM/S system in Navy leadership roles were also important.

Manufacturing of the first LPD 17 AEM/S System components began on March 23, 2000. (Camponeschi and Wilson 2001) *U.S.S. San Antonio* (LPD 17) was commissioned on January 14, 2006. The AEM/S System was specified for the following ships of the class via class specific Government Furnished Information (GFI) and reference to the engineering drawings for the lead ship of the class.

The Advanced Enclosed Mast can be evaluated against the criteria established by Doerry (2006) for institutionalizing a technology:

• **Demonstrate the Technology Early:** The technology was successfully demonstrated on U.S.S. Radford between 1997 and 1999.

• **Incorporate the basic technology into production units**: The technology was incorporated in production units on the LPD 17 class. Much of the technology has also been incorporated into the DDG 1000 deckhouse.

• **Establish a common architecture and interfaces**: Currently each application is a custom design to meet ship requirements.

• **Establish a common design processes**: Currently each application employs a custom design process to meet specific ship requirements.

• **Incorporate the architecture and design processes into design tools**: Existing design tools can analyze proposed structures, but synthesis tools generally do not exist. Standardized methods to analyze a composite structure have not been codified.

• **Codify the practice in Government or Industry specifications, standards and guides**. The participants have done an excellent job capturing the technology in a number of technical documents that are generally available within the community. High level requirements have been codified in the Naval Vessel Rules, but much work remains for detailed practices. The shipyard fabricators have developed dozens of production procedures, but most are of a proprietary nature and are not shared with other shipbuilders.

• **Teach the architecture and design process as part of a typical Engineering School Curriculum**. Basic composite structural design is introduced at the undergraduate level at a number of universities. More advanced courses are generally taught at the graduate level. There are few courses that teach naval applications of composite structures.

6.2 Hybrid Electric Drive on LHD 8

Figure 13: U.S.S. Makin Island (LHD 8)

The hybrid electric drive (HED) on U.S.S. MAKIN ISLAND (LHD 8) (Figure 13) is an excellent example of a technology that transitioned directly from industry without involving the S&T community. It is also a technology that has not been fully institutionalized. In an HED system, a gas turbine mechanical drive shaft is augmented with a relatively small propulsion motor powered from diesel generators (Figure 14). At low speeds, the fuel efficiency of the diesel electric drive motor is much greater than fuel efficiency of the gas turbine operating at a small fraction of its rated load.

A form of HED predated MAKIN ISLAND by over a decade. The first U.K. Type 23 frigate, H.M.S. NORFOLK was commissioned in 1990. These frigates employed a COmbined Diesel-eLectric And Gas turbine (CODLAG) propulsion system. Low power diesel electric propulsion is employed for low speed quiet anti-submarine warfare (ASW) operations. For high speed, gas turbine boost engines are brought online. Details of the Type 23 design were well known to U.S. Navy engineers. Attaining this knowledge was greatly facilitated by information exchange agreements between the U.S. Navy and the Royal Navy.

As reported by Hatcher et al. (2002), the LHD 8 HED had its origin in feasibility studies conducted to evaluate the conversion of steam propulsion to gas turbine propulsion on an LHD. The first study (Ingalls 1997) concluded that converting LHD 7 to gas turbine propulsion using an LM2500+ gas turbine to power each shaft was feasible. This design included an 800 HP loitering motor integrated with each reduction gear. These loitering motors would improve fuel efficiency by allowing the gas turbines to be shut down while the ship was in the Amphibious Operating Area. The loitering motors would provide enough power to achieve roughly 5 knots. Because this study left the electric plant at 450 V, steam heat provided by auxiliary boilers would be retained to supply the over 7 MW of ventilation heating loads on cold days. The study recommended that follow on LHDs (LHD 8) consider using a 4160 Volt electrical distribution with six 4MW generators to supply the ventilation heater loads.

When this concept was briefed to the Commander, Naval Surface Force Pacific Fleet, he stated that he would support a gas turbine LHD only if all of the steam systems were removed. This eliminated any further consideration of a 450 V distribution system due to circuit breaker limitations, extremely restrictive plant configurations, and the excessive weight of distribution cabling.

A second study (Ingalls 1998) recommended converting the electric plant to 4160VAC with six 3.75 MW generators and integrating two 1,000 HP loiter motors with each reduction gear. 4160 VAC was recommended because of its commonality with the aircraft carrier systems, the reduction in risk of qualifying components, and the flexibility in plant configurations. The increased size of the loitering motors enabled a higher speed of 10 knots. These two motors would drive the 1st reduction gear, but would be mounted on the 2nd reduction gear housing. The fuel savings attributed to these motors was estimated to be over $22M during the 40 year service life of the ship. This study recognized that even with one generator out of service for maintenance, there would be enough electrical capacity on all but the coldest days to provide power to the four 1,000 HP motors.

A third study (CSC 2000) recommended integrating a single 5,000 HP induction motor with each reduction gear. The recommended motors were 1800 rpm single speed induction motors. Adjustable speed drives were not recommended because of the risk of increased harmonic currents and voltages causing problems in electric plan operation. The 5,000 HP motors would enable the ship to achieve 13 knots on the motors and nicely matched a 4 MW rating for a single diesel generator set. Although not a requirement, this increased speed enabled the motors to be used during LCAC operations. The combined power demand of the two motors also was less than the excess electrical generation capacity on all but the coldest of days. The payback time for the 5,000 HP motor was estimated to be less than two years. As a side note, this study directly referenced the U.K. Type 23 frigate as a previous example of HED.

A fourth study (Converteam 2001) reflected the evolving electric plant design which replaced the 3.75 MW diesel generators with 4.0 MW diesel generators. This study also recognized a shaft break-away torque requirement. Previous studies required the shaft to be spinning before energizing the propulsion motor. This would normally require the gas turbine to start shaft rotation, then transfer propulsion load to the motors. This concept of operation received significant negative feedback from fleet operators during fleet reviews. With only one gas turbine per shaft, the fleet was concerned should that one gas turbine become inoperative during restricted maneuverability or alongside a pier, the ship would be unable to break the shaft free and use the motor. The requirement to develop shaft break-away torque was subsequently added to the HED. This requirement, and a more detailed analysis of the electrical system led to the recommendation to use a commercially derived 24 pulse variable speed drive (VSD) with an 1800 rpm induction motor. The proposed drive would meet MIL-STD-1399-300 electrical power quality requirements.

Dalton et al. (2002) reported that the VSD drive alleviated the need to have 3 paralleled generators to provide inrush current if a soft start capability (provided by the VSD) were not provided. The VSD enabled either a single dedicated generator to power the power, or for two paralleled generators to simultaneously power the motor and serve ship service loads while meeting power quality requirements.

During the design development of the LHD 8 HED, the use of non-developmental components was repeatedly stressed. Technologies such as permanent magnet motors and advanced drive concepts were discarded because of their perceived risk. The innovation in the LHD 8 HED was not

in the component technologies, but rather in the integration of proven components into the overall propulsion system that enabled a significant improvement in fuel efficiency.

This final configuration was incorporated into the ship specifications for the detail design and construction contract for LHD 8. Because the design incorporated non-developmental components, no prototypes were produced. There was no land based testing of the integrated propulsion system, and no integrated testing of the Machinery Control System prior to commissioning of the Auxiliary Propulsion System onboard the ship.

From a requirements perspective, the joint ASN(RDA) and DCNO(N8) memo that approved gas turbine propulsion for LHD 8 (Buchanan and Lautenbacher 1999) specifically referenced a "loiter motor drive;"

> "The capability to operate in a loiter motor drive mode at speeds approaching 10 knots offers redundancy and the potential for significant fuel savings when compared to a steam ship."

This statement was interpreted by the Program Office (PMS 377) as a hard requirement for HED on LHD 8. During the summer and fall of 2001, a number of descoping efforts were taken to reduce the acquisition cost estimate to match the available funding. The HED was protected from being descoped by the above statement in the joint memo. Because HED is not tied specifically to any mission area, it is unclear whether HED would have been descoped had the requirements memo not included it.

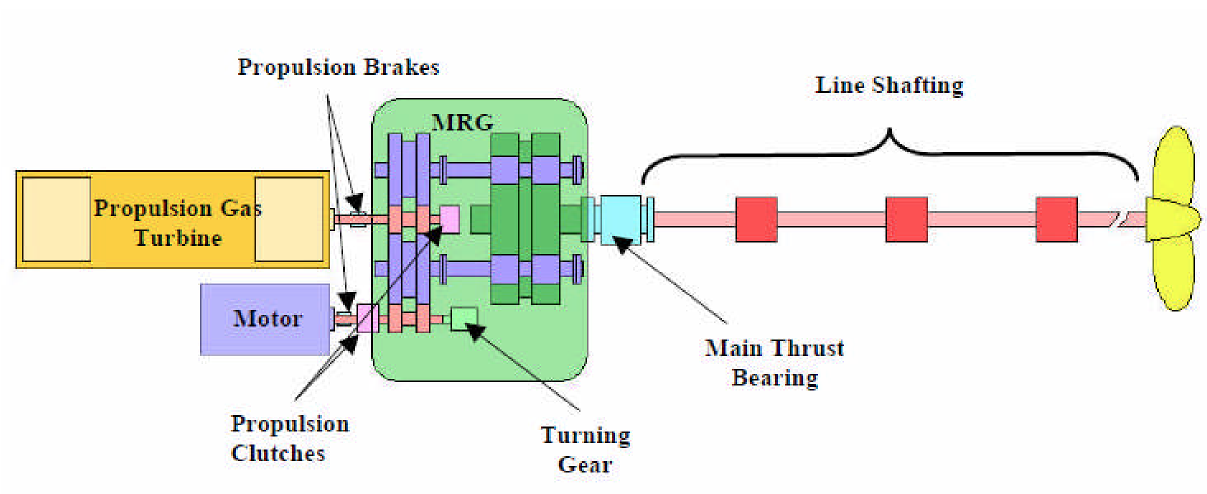

Figure 14: U.S.S. Makin Island (LHD 8) Hybrid Electric Drive

The design, production, integration and testing of the HED on LHD 8 was challenging. Frequent communication among the Navy engineers, shipyard engineers, and the OEM engineers, many hours of testing and system grooming, and two sets of builders trials followed by acceptance trials finally resulted in the Navy accepting delivery of LHD 8 and its HED on April 16, 2009. Additional grooming was conducted on her voyage from the shipyard to her homeport in San Diego, California. U.S.S. MAKIN ISLAND was commissioned on October 24, 2009. During his speech at the commissioning ceremony the Honorable Ray Mabus, Secretary of the Navy, remarked ...

> "Just two months ago, the Makin Island, our hybrid of the seas that uses an electric motor to power the ship at low speeds, went from where it was built in Pascagoula around to its homeport in San Diego. During that initial voyage alone, she saved close to $2 million in fuel costs. NAVSEA estimates at today's fuel prices the Makin Island will save $250 million over the lifetime of that ship, and it doesn't include reduced maintenance costs..."

Hybrid Electric Drive can be evaluated against the criteria established by Doerry (2006) for institutionalizing a technology:

• **Demonstrate the Technology Early:** The basic concept was demonstrated by the Royal. Navy in the Type 23 frigate.

• **Incorporate the basic technology into production units**: Production Hybrid Electric Drive systems were produced and installed on LHD 8. Ships of the LHA 6 class will also employ the same design.

• **Establish a common architecture and interfaces**: While efforts are currently underway to demonstrate HED on a DDG 51 class ship, a common architecture and common interfaces are not being developed. Each application of HED is treated as a new project.

• **Establish a common design processes**: A standardized design process for Hybrid Electric Drive has not been established.

• **Incorporate the architecture and design processes into design tools**: Current machinery design tools and ship synthesis tools such as ASSET can not directly model HED. Work-arounds to enable these tools to model HED have been developed.

• **Codify the practice in Government or Industry specifications, standards and guides**. Hybrid Electric Drive is not specifically addressed in Government or Industry specifications, standards, and guides. Hybrid Electric Drive is currently implemented in project unique specifications.

• **Teach the architecture and design process as part of a typical Engineering School Curriculum**. While the basic concept is presented to naval architecture students, details are not because of the lack of common design process and architecture.

6.3 Integrated Power System and Next Generation Integrated Power System

6.3.1 Integrated Power System on DDG 1000

Figure 15: Artist Rendering of Zumwalt (DDG-1000)

On January 06, 2000, The U.S. Navy issued the following press release (No. 007-00)

> "The Department of the Navy announced today that the Land Attack Destroyer (DD 21) will be its first class of ships designed and built during the 21st century to be powered by electric drive featuring an integrated power architecture. The first of the DD 21 class of destroyers is expected to be in commission by the end of this decade.
>
> Underscoring the importance of using integrated power technologies, Secretary of the Navy Richard Danzig said, "Changes in propulsion systems fundamentally change the character and power of our forces. This has been shown by the movement from sail to steam or from propeller to jet engines or to nuclear power. Electric drive will reduce the cost, noise and maintenance demands of how our ships are driven. More importantly, electric drive, like other propulsion changes, will open immense opportunities for redesigning ship architecture, reducing manpower, improving shipboard life, reducing vulnerability and allocating a great deal more power to warfighting applications."
>
> Major benefits related to electric drive are derived in two areas, warfighting capability and quality of life for sailors. In terms of warfighting, this technology represents significant increases in stealth capability through signature reduction, and a large increase in available power that is seen as critical to future weapons systems that will be aboard Navy ships. Electric drive technology also represents great potential to improve the quality of life for embarked sailors. It will free up large amounts of internal space, leaving room for significant habitability improvements.

The key design element of integrated power and electric drive is a single source generator for the requirements of all ship's power needs, including propulsion. One of the most attractive elements of the design is the resultant elimination of the drive shaft and reduction gears found in traditional Navy ships. The Department of the Navy decision to team DD 21 with electric drive for its propulsion comes after careful consideration among several possibilities studied by the two contractor teams involved.

Secretary Danzig said also, “This is a long sought and much desired goal. DD 21 will truly be the first 'Smart Ship' built from the keel up. Electric drive technology is integral to that. The warfighting and quality of life benefits that can be derived from this will mean that our sailors can walk aboard a ship that is unlike any other they have known... this shift in propulsion reflects our wider efforts to change the very culture of the Navy. With DD 21, Sailors will live, work, and fight aboard a ship that values them like never before.”

While the DD 21 program would later transform into the DDG-1000 program (Figure 15), the commitment to the Integrated Power System continued. DDG 1000 is under construction and incorporates the Integrated Power System. DDG 1000 is currently scheduled to deliver to the Navy in 2013.

While a number of studies and projects in electrical propulsion and electrical power system technology where conducted in the 1960’s and 1970’s, the efforts leading to incorporating IPS on DDG 1000 can probably be best traced back to November 1979 with a series of studies of the then available technology under the Advanced Integrated Electric Propulsion Plant Conceptual Design (AIEPP) project managed by NAVSEA (Joliff and Greene 1982). During the early 1980’s the Navy began the design of DDGX (future DDG 51 class). Heavily influenced by AIEPP, electric drive was chosen as the baseline propulsion system during the preliminary design of DDGX. This decision however, was reversed in Contract Design due to concerns over cost and schedule risk as well as a perceived lack of expertise within the Navy and Industry design and engineering workforce. As a result, the traditional mechanical drive plant used in the DD 963 and CG 47 class was employed in the DDG 51 class. Many universities in the United States during the 1970’s and 1980’s dropped electrical power curriculums and research groups because the field was considered “mature.” Hence the concern for workforce expertise was well founded.

Because the advantages of electric drive were recognized, senior leaders in the Navy’s Engineering Duty Officer community (particularly CAPT Clark (Corky) Graham and RADM Millard Firebaugh) began to encourage young officers going through the Naval Construction and Engineering (13A) program at MIT to work on a second Masters Degree in electrical engineering and conduct research in electric drive related areas. Typically 1 to 3 officers a year would take on this challenge. During the late 1980’s and early 1990’s, three officers (LT Norbert Doerry, LT John Amy, and LT Tim McCoy) would also continue on to earn a PhD in naval electrical power system related areas. Later, the Naval Post Graduate School would create a curriculum in power systems engineering that would also contribute to the talent pool. These MIT and NPS trained officers, teaming with the civilian experts at the Naval Surface Warfare Center, Carderock Division detachment in Annapolis (Annapolis Lab), the Naval Surface Ship Engineering Station (NAVSSES) in Philadelphia, NAVSEA Headquarters in Crystal City, VA (and later in the Washington Navy Yard in D.C.), and industry would develop the IPS concept and gain the greater Navy’s confidence that electric drive was ready for the next major combatant design. In many cases, these officers played

the role of Relationship Managers. During their normal duty rotations and in their post-Navy careers, they would become part of the different technology transition communities: Resource Sponsor, Science & Technology, Acquisition and Engineering, Fleet, and Industry. Rather than "outsiders" trying to sell an idea to these communities, these "insiders" where able to serve as ambassadors for the technology within their own organizations.

In September 1988, Chief of Naval Operations Adm. Carlisle A.H. Trost stated in a speech to the Navy League:

> "Integrated electric drive, with its associated cluster of technologies, will be the method of propulsion for the next class of surface battle-force combatants, and I am directing all the major Navy organizations involved in these efforts to concentrate their energies toward that objective."

Aligned with this declaration, the Integrated Electric Drive (IED) Program emerged to develop a very quiet and power dense electric propulsion system for a future surface combatant. General Electric Co. was awarded a contract to develop prototype hardware in November 1988. This hardware included a 120 Hz., 6 phase, 4160 vac, 25 khp 3600 rpm very quiet rotating machine that could serve as either a generator or as a geared propulsion motor.

In 1991, the Soviet Union collapsed, ending the Cold War. With the end of the Cold War and the nation's desire for a "Peace Dividend," the Navy could no longer afford to develop a future surface combatant (The DDG 51 class having just been introduced). The IED program found itself developing an expensive technology that did not have an obvious home. In 1991, the IED program came under the Advanced Surface Machinery Programs (ASMP) under the direction of Captain Corky Graham and Cy Krolick.

In the fall of 1991 and spring of 1992, considerable effort was expended by the ASMP engineers to reduce the cost of the IED system and to take advantage of commercial technology. ASMP direction was to change the program objectives from increasing military effectiveness at greater cost to making systems more affordable without degrading performance (Figure 16). These studies concluded that with the expected relaxing of acoustic requirements, other technologies could produce more affordable power system than what was achievable with the IED system under development. Consequently, ASMP focus shifted away from completing the IED program. Some IED hardware was delivered to the Navy, but never tested.

In early 1992, the concept of Power System Baselines was developed (Figure 17). If the Navy needed to develop a power dense, quiet electric drive system in the near term, then ASMP would propose a system based on the IED program. This set of technology was called "Baseline 1" and reflected the current program of record. Since an affordable system for an amphibious warfare ship or auxiliary ship could not be based on "Baseline 1," a power system based on militarizing commercial technology would be proposed. This was called "Baseline 2." These baselines would be supported by specifications, standards, handbooks, design data sheets, and design tools. Ongoing S&T and R&D efforts would eventually result in "Baseline 3" replacing "Baseline 1" with a more affordable power system architecture for combatants, and a future "Baseline 4" would similarly replace "Baseline 2" for amphibious warfare and auxiliary ships. These baselines anticipated the Product Line approach to technology development.

In 1992, the basic architecture of IPS and the different module types were established. Doerry and Davis (2004) described the IPS architecture:

> "The Integrated Power Architecture (IPA) provides the framework for partitioning the equipment and software of IPS into modules. IPA defines six functional elements and the power, control and information relationships between them. Every IPS module corresponds to one of the IPA functional elements. A power relationship is one involving the transfer of electrical power between two functional elements. A control relationship refers to the transmission of commands from one functional element to another while an information relationship refers to the transmission of data from one functional element to another. The six functional elements are Power Generation, Power Distribution, Power Conversion, Power Load, Energy Storage and System Control."

The IPS concept in 1992 also included a "Product Line" approach. Generalized modules would be engineered ahead of their application for a specific ship. These modules would be described by Module Characterization Sheets which provided the necessary information to integrate them into a system as well as the necessary specifications and standards to procure the modules. As shown in Figure 18, an IPS Design Data Sheet would provide the process for developing an IPS configuration by tailoring the individual modules to meet the ship requirements.

IPS also incorporated provisions for AC zonal distribution system and DC zonal distribution for ship service loads. A modified version of the AC zonal distribution system was later incorporated in the Flight IIa of DDG-51, LPD 17, and LHD 8. The DC zonal distribution system became the Integrated Fight Through Power (IFTP) system that transitioned to DDG 1000 as part of IPS.

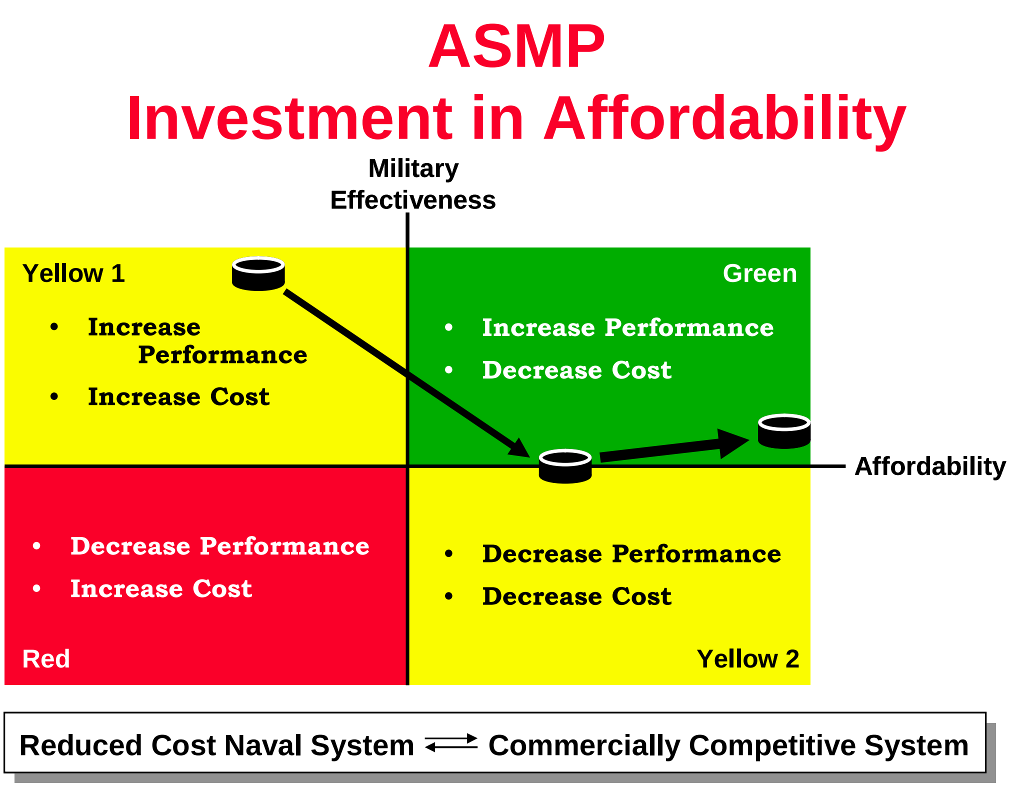

Figure 16: ASMP Redirection to Affordability from Military Effectiveness

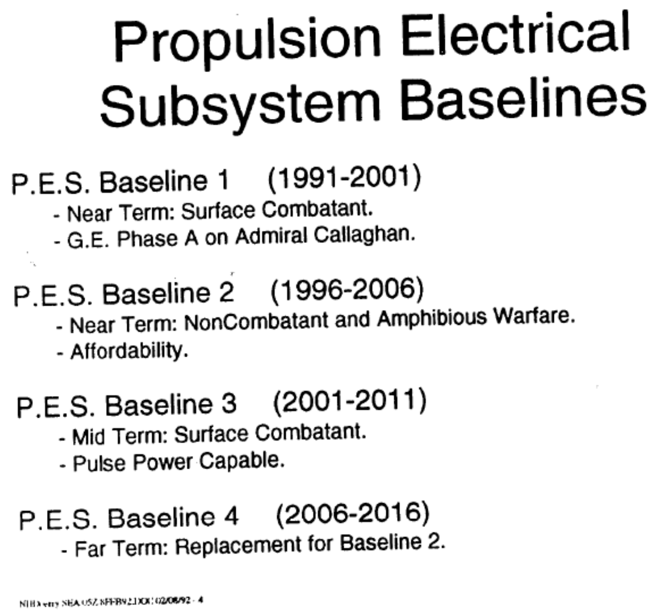

Figure 17: ASMP Power System Baselines

During 1992, ASMP also began discussions with Newport News Shipbuilding and Kamen Electromagnetics to develop a "Baseline 3" power system based on Permanent Magnet Motor technology. This technology promised to provide the power density combatants would need at a cost lower than what could be provided by "Baseline 1." "Baseline 3" was also intended to be capable of supporting future pulse power weapons such as lasers and rail guns. To demonstrate the Permanent Magnet Motor technology, ASMP established a Reduced Scale Advanced Development (RSAD) project that in 1994 resulted in the testing of a 3,000-hp permanent magnet motor scaled as a prototype of a 25,000-hp motor.

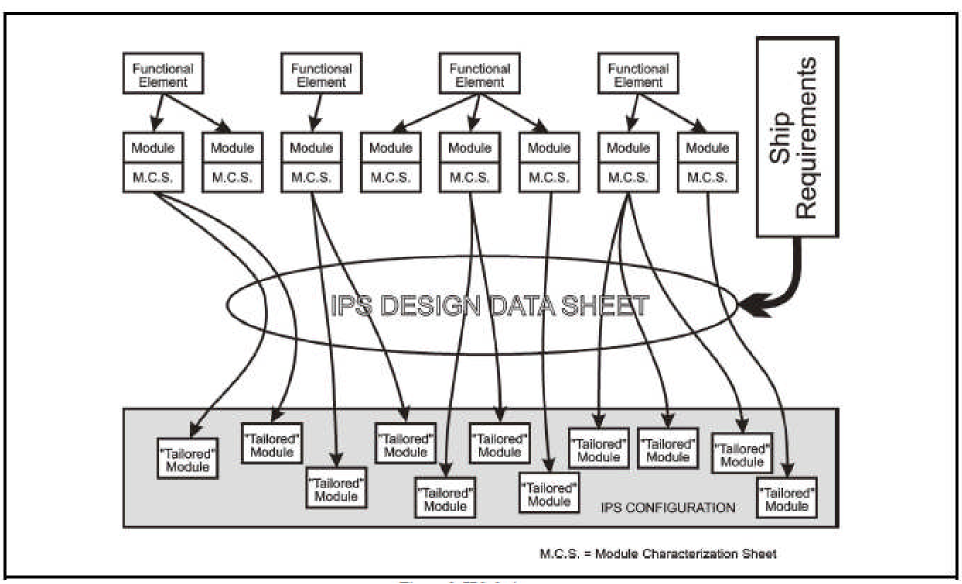

Figure 18 IPS Integration Process

In the fall of 1992, ASMP decided that since "Baseline 1" was unaffordable, and "Baseline 2" didn't really need any further development, that IPS would focus entirely on "Baseline 3." Hence IPS became the program for developing an Integrated Power System concept that could be employed on the next combatant. Auxiliary ships, such as the T-AKE 1 class, would use commercial marine IPS solutions, fulfilling the "Baseline 2" concept. In 1993 work began on developing a statement of work and specification for the IPS Full Scale Advanced Development (FSAD).

In February 1995 NAVSEA awarded the IPS FSAD contract to Lockheed Martin's Ocean, Radar, and Sensor Systems. Lockheed Martin became the systems integrator The FSAD system was intended to serve as a test bed for technologies that could be incorporated in a future shipboard IED architecture. Lockheed Martin was also responsible for developing the standards, specifications, design data sheets, and handbooks for designing and integrating an IPS system. Unfortunately, while Lockheed Martin was an outstanding Systems Engineering organization to develop specific products, it was not a company accustomed to developing a product line. Much effort was expended to transition the knowledge gained in the Systems Architecting process conducted by the ASMP Government team to help the contractor fulfill the envisioned role of IPS systems integrator. The mismatch between the needs of a product line developer and the capability of a product developer was not resolved. Following the IPS FSAD contract, Lockheed Martin exited the IPS market.

In June 1996, an SC-21 (predecessor to the DDX program) IPS Ship Impact Study compared IPS and Mechanical transmissions. This study, conducted by the SC-21 Cost and Operational Effectiveness Analysis (COEA) Team showed the IPS ship cost $10M less in acquisition, was 400 LT smaller, and consumed 17% less fuel. In March 1998, the SC-21 COEA report by CNA concluded IPS resulted in "Significant reductions in ship design, construction and life cycle costs"

The integration of IPS into the DD-21 program was described by Walsh (1999):

> "In early 1999, senior Navy officials -including Adm. Frank L. Bowman, director of the Navy's nuclear propulsion program, supported by Vice Chief of Naval Operations Adm. Donald L. Pilling; Vice Adm. George P. Nanos Jr., NAVSEA commander; Rear Adm. George R. Yount, deputy for engineering in NAVSEA; and Rear Adm. Joseph A. Carnevale Jr., program executive officer for the DD-21- initiated an effort to accelerate Navy electric drive work. In 1998, the IPS program was transferred from NAVSEA's Engineering Directorate to the PEO DD-21 (PMS-500). The fiscal year (FY) 1999 Navy budget provided $33.9 million for IPS, $4 million of which was targeted for the DD-21 Blue and Gold team concept studies. No funding was provided in the FY 2000 budget, however. Navy leaders are considering options for reprogramming funds from other programs for lED work during the year ahead."

As previously discussed IPS became part of the DD-21 baseline in 2000. One consequence of moving IPS into a ship acquisition program was that the effort became focused solely on this one transition. The product line approach was largely abandoned as focus was placed on producing a product for the DD-21 and later the DDX / DDG-1000. The module boundaries defined in 1992 were redefined into a ship specific Low Voltage Power System (LVPS) (Figure 19) developed by

DRS Technologies and a High Voltage Power System (HVPS) (Figure 20) developed by Converteam. While a test facility (Figure 21) and a working Integrated Power System were developed, the vision for an IPS Product Line was not realized.

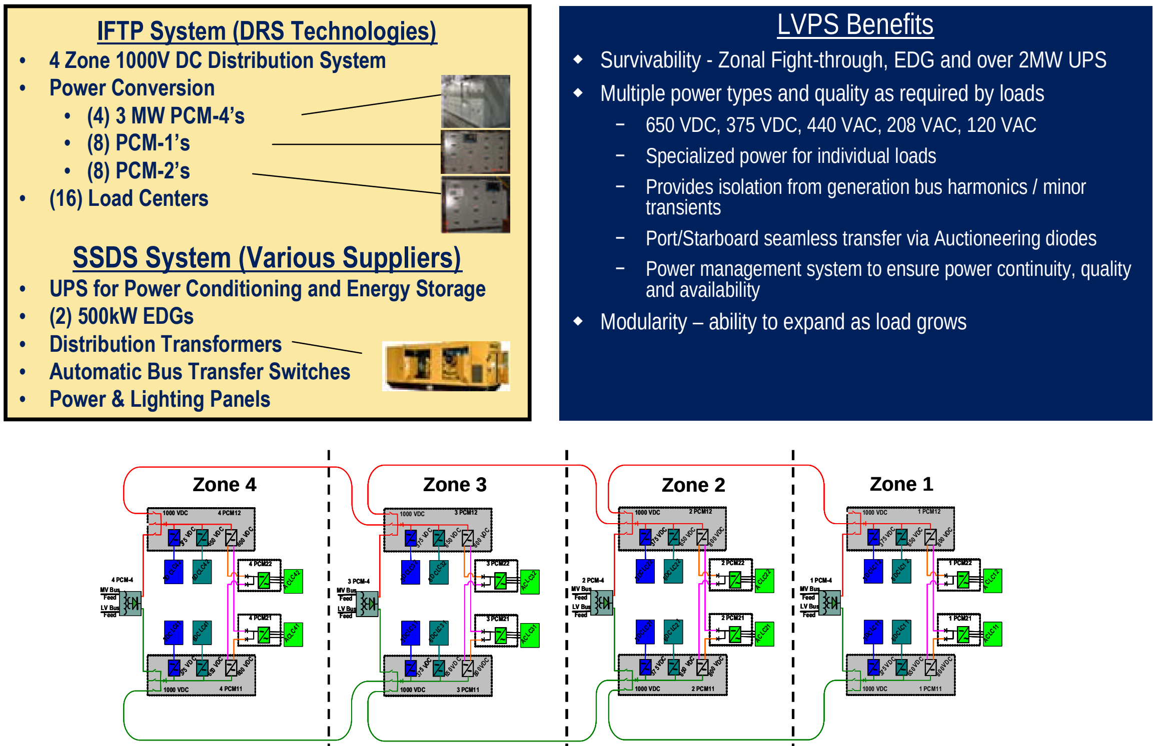

Figure 19: DDG 1000 Low Voltage Power System (LVPS)

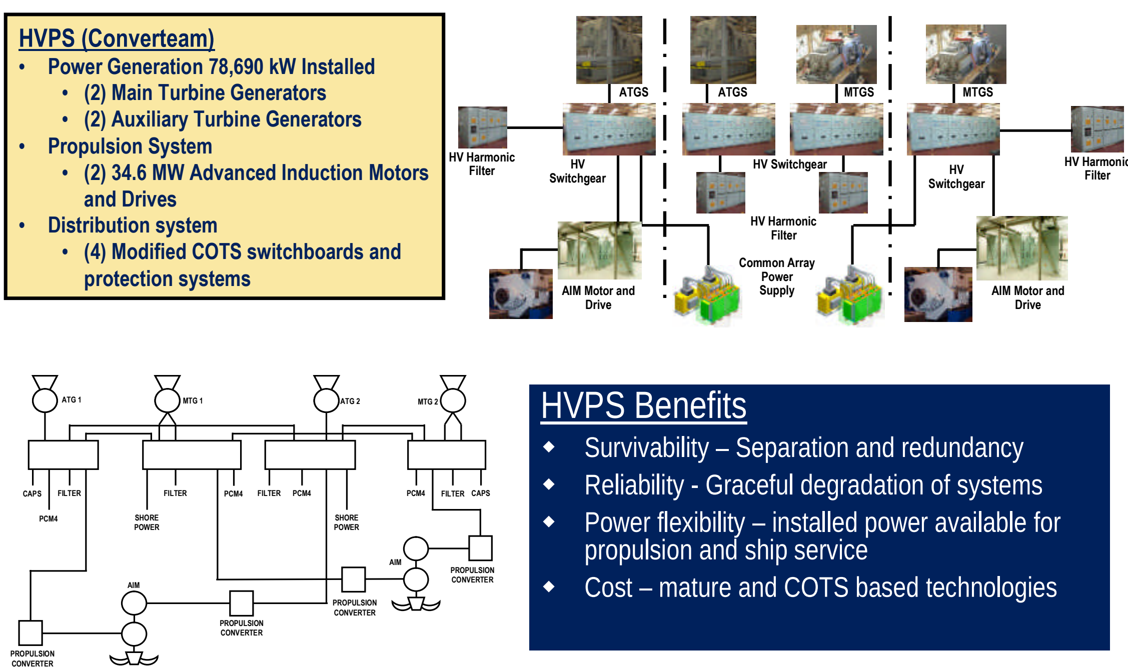

Figure 20: DDG 100 High Voltage Power System

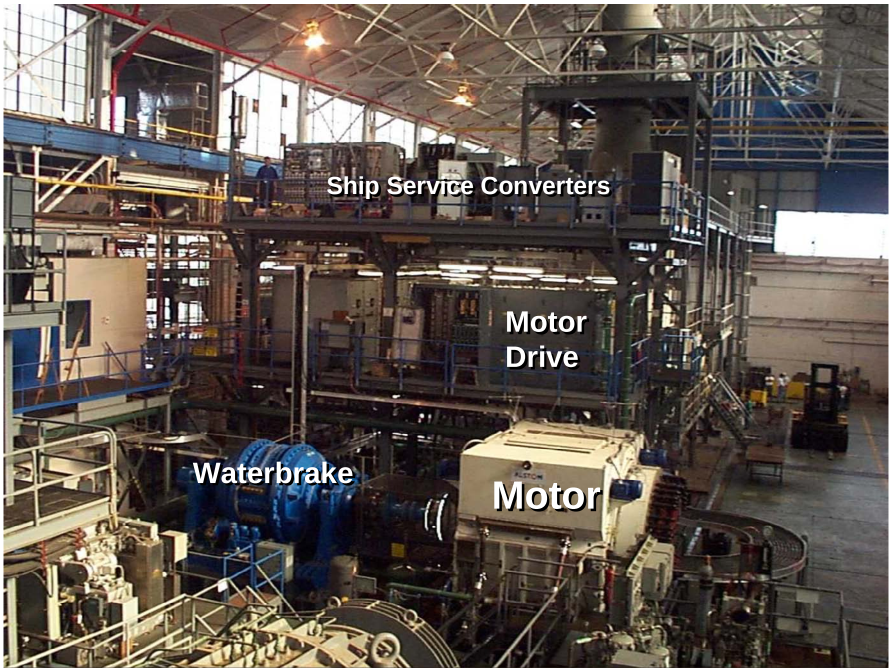

Figure 21: IPS Test Facility at NSWC Philadelphia

6.3.2 Next Generation Integrated Power System

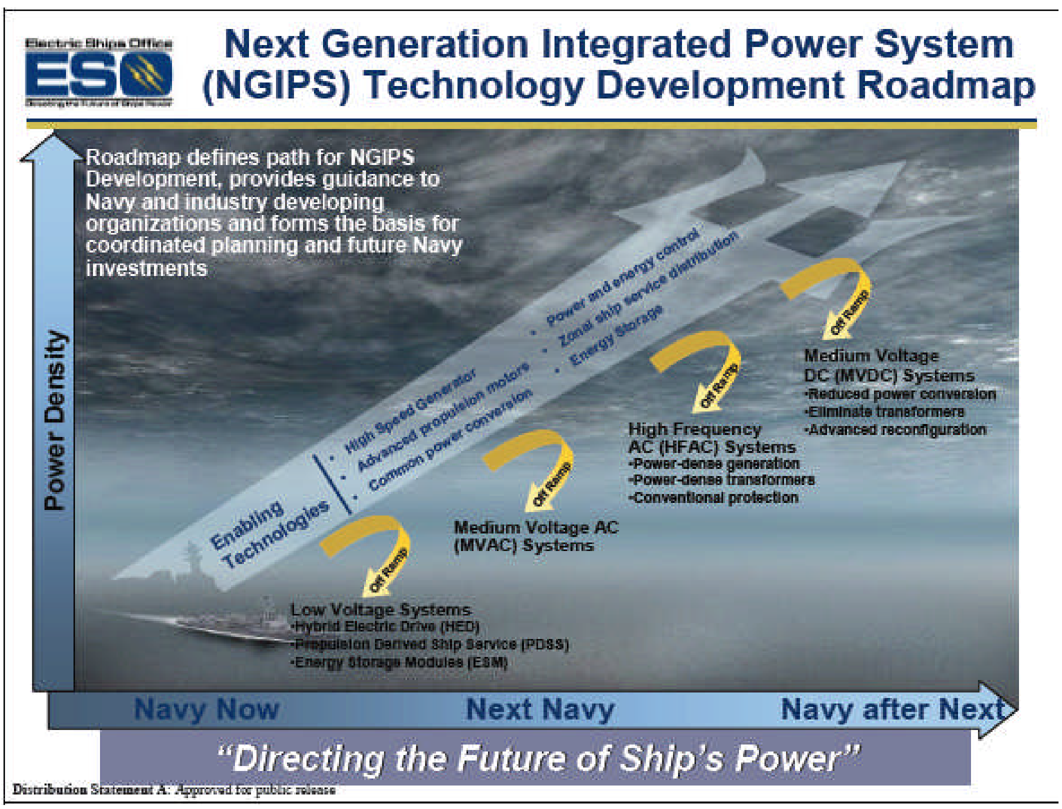

Figure 22: NGIPS Technology Development Roadmap of 2010

The Next Generation Power System, led by the Electric Ships Office (PMS 320) is establishing a product line approach to integrated power systems (Figure 22). NGIPS has its origins in the transfer of the IPS program from NAVSEA's Engineering Directorate to PEO DD-21 (PMS-500) in 1998. There was general concern that without a corporate approach to IPS development, the ability to use common elements across ship types would be severely limited. Following a study of the different alternatives, the Commander, Naval Sea Systems Command signed out a report on Jan 21, 1999 that recommended a Corporate Development Program for IPS. This Corporate Development Program, concurred to by SEA 03 (Now SEA 05), SEA 08, PEO DD21, PEO SUBS, and PEO CV, would develop a product line approach to benefit multiple platforms (Figure 23). This report also observed that the Radial-gap Permanent Magnet Motor was the most viable motor common to the broadest range of ships.

On February 18, 1999 the Integrated Power System Corporate Investment Board (CIB), composed of the NAVSEA and PEO organizational stakeholders, met to discuss the recently signed out report and the strategy for funding this program. A $503M program schedule and budget (Figure 24) was proposed. This proposal to stand up a new program with such a large cost was not well received by OPNAV and the concept of a Corporate IPS Program was shelved.

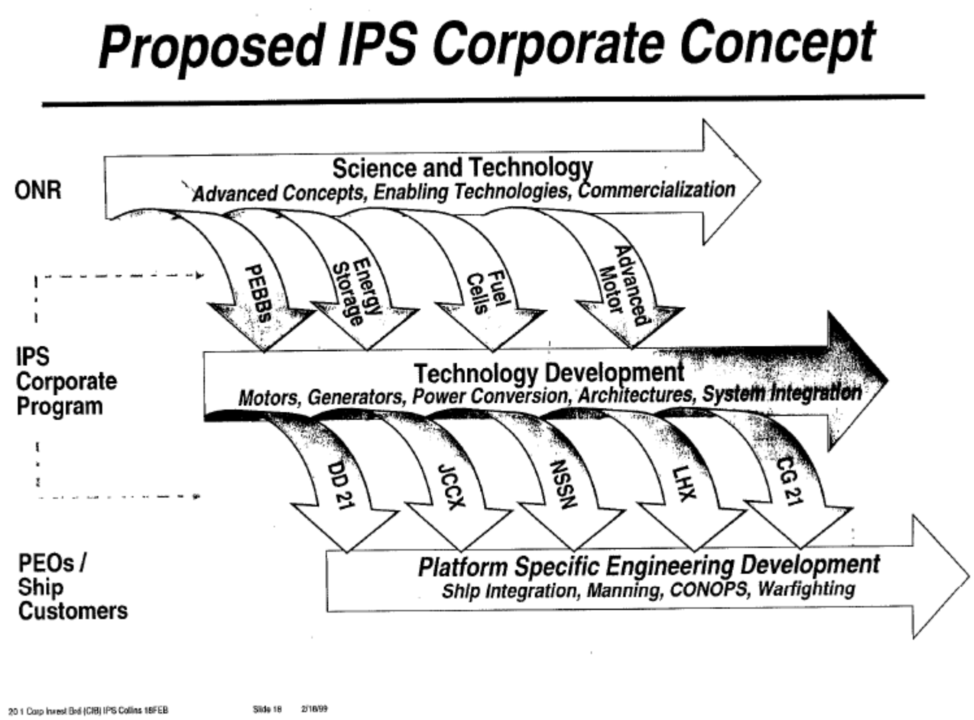

Figure 23: IPS Corporate Development Program Product Line Approach

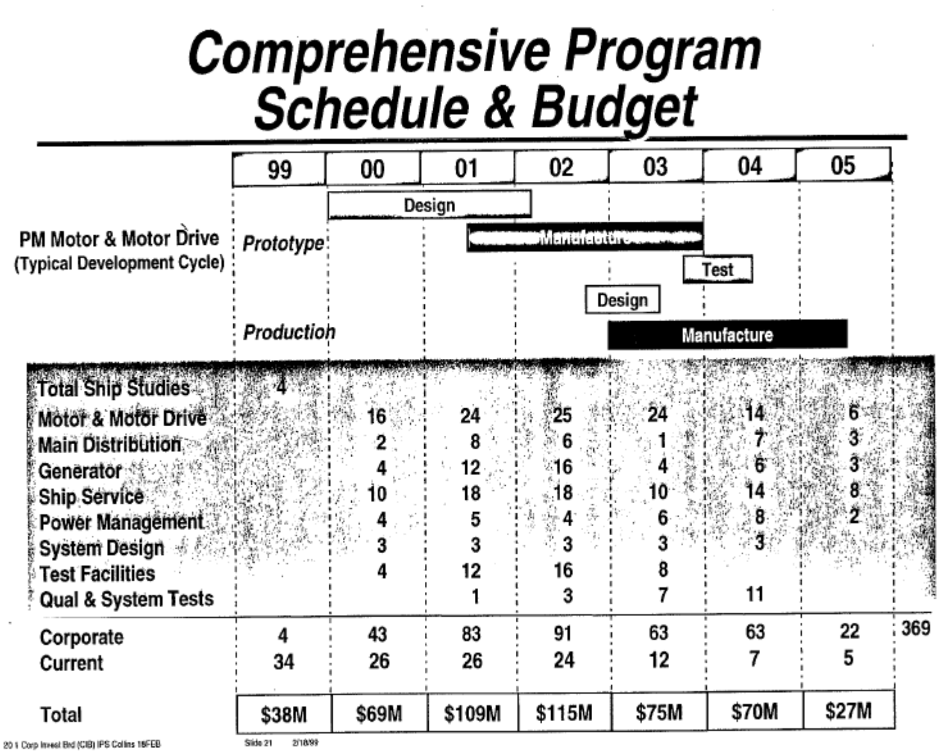

Figure 24: Corporate IPS Program Schedule and Budget

For the next five years, IPS activity concentrated on supporting the DDG 1000 program. As the basic design for the DDG 1000 IPS neared completion in 2005, Navy interest in other applications of IPS grew. On 15 June 2006 a CNO Flag Steering Board for a Next Generation Integrated Power System (NGIPS) formed. This Flag Steering Board differed from the previous Corporate Investment Board in that it also included representatives from OPNAV and the Chief of Naval Research (CNR). This Flag Steering Board would also interact with senior industry leaders to ensure the concept had broad support.

During the summer and fall of 2006, NGIPS working groups met to develop the NGIPS Concept as well as program schedules and costs. Potential applications included a new cruiser (CGX), submarines (future SSN Flight, or SSBNX), future destroyer (DDGX) or Amphibious Warfare Ship (LSDX). Multiple time-phased architectures, reminiscent of the IPS "Baselines" were developed. Meetings with Industry and the shipyards helped ensure there was a broad understanding of NGIPS goals as well as enabling industry to communicate the art of the practical and possible to the government. A number of program schedule and budget options to implement NGIPS were developed. As before, these proposed budget ranged from roughly $100M to $300M. While OPNAV was very interested in the technology, OPNAV was not enthusiastic in finding the funding.

On January 14, 2007 a stop work was issued for the third Littoral Combat Ship (LCS 3) because of cost growth. The LCS 3 contract was terminated on April 13, 2007. A stop work for LCS 4 was issued in November 2007 because of inability to renegotiate revised (fixed-price) contract terms for LCSs 2 and 4. Due to the austere fiscal environment, there was a lack of resource support for a new large corporate investment. Consequently, focus shifted in 2007 to producing a Technology Development Roadmap with the goal of minimizing new NGIPS investments by aligning already

funded investments at ONR and elsewhere to achieve the NGIPS objectives. During this time, an open architecture business model was also developed.

In 2007 the Flag Steering Board recognized that this new model for coordinating already existing programs required a coordination office. Hence support grew for an Electric Ships Office (ESO) to coordinate existing activities as well as manage programs to "fill in the gaps." There was much debate as to the "home" organization for this office. The two options that were most favored were a program office in PEO-SHIPS and a program office in NAVSEA SEA 05. The final consensus would be for the ESO to reside in PEO-SHIP but represent Electric Ship interests for all PEOS. SEA 05 would provide direct technical support, much as a SEA 05 Ship Design Manager provides direct technical support to ship acquisition programs. This arrangement would ensure that the ESO would engage technical authority and program authority stakeholders. Finally, on November 13, 2007, ASN(RDA) directed PEO-SHIPS to establish the Electric Ships Office. On November 30, 2007, the Electric Ships Office (PMS 320) was established.

On November 30, 2007 SEA 05 issued the NGIPS Technology Development Roadmap. This roadmap would be endorsed by the NGIPS Executive Steering Group (An evolution of the Flag Steering Board) on December 7, 2007. This roadmap featured three power generation architectures (Medium Voltage AC, High Frequency AC, and Medium Voltage DC) and a zonal electrical distribution system (ZEDS) architecture based in part on the DDG 1000 Integrated Fight Through Power (IFTP) (Figure 25). The Roadmap defined the state of the technology, defined the need for integrated power systems, defined the power system architectures, listed technology development needs, and proposed an open-architecture based business model. It did not define an execution plan. Some important lessons learned from the development of this roadmap include:

- Engagement of all the technology transition participants (stakeholders) is important
- Stakeholder alignment is as important as the document. The roadmap has no "enforcement" mechanism, so it is important that all stakeholders follow the roadmap voluntarily. Getting the endorsement of the ESG was very important to its success.
- Distribution Statement A (approved for public release with unlimited distribution) is important because it facilitated a shared vision throughout academia, industry, and the Government.

In 2008, the ESO contracted with the Northrop Grumman Shipbuilding (Both Newport News and Pascagoula yards) and General Dynamics (Both Bath Iron Works and Electric Boat) to team together to evaluate the risks associated with the NGIPS Technology Development Roadmap. This shipyard team would prove to be a good method to transition NGIPS technology to the industry that would integrate it into the detail design and construction of future ships. In 2009 this team would produce a draft NGIPS Conceptual Design Application Handbook and in 2010 a NGIPS Conceptual Design Zonal Electrical Distribution System (ZEDS) Application Handbook

The NGIPS Technology Development Roadmap also served well to steer the S&T initiatives at ONR as well as within academia. The Electric Ship Research and Development Consortium (ESRDC) produced many academic papers and theses to explore the different risk areas identified in the roadmap. At ONR, the NGIPS S&T efforts (as described on the ONR web site) concentrated on topics included in the roadmap:

- Advanced Naval Power Systems Modeling and Simulation

- High density energy storage
- Advanced power generation to reduce fuel consumption
- Diagnostics that clearly define the fault severity and accurately locate the fault and Prognostic Capability that reliably foretells the future condition of the equipment and system
- Advanced power converter topologies
- Application of advanced semiconductors
- Power system control architectures
- Power and energy management methodologies
- Dynamic stability analyses

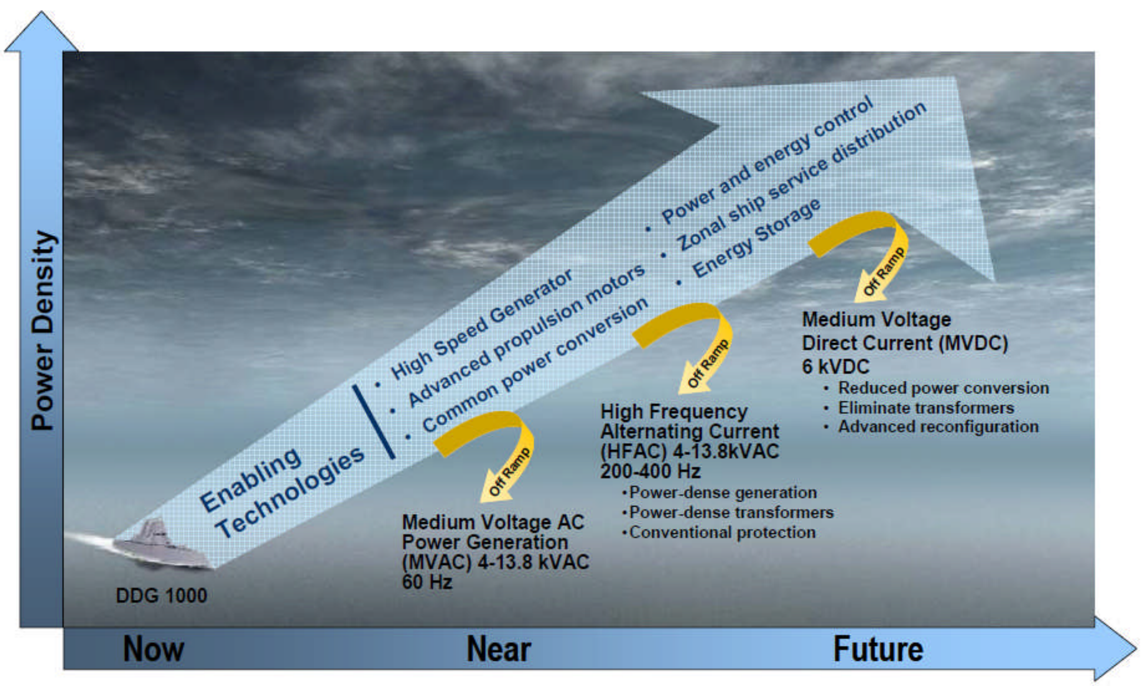

Figure 25: NGIPS Technology Development Roadmap of 2007

The NGIPS Technology Development Roadmap also resulted in increased interest in developing IEEE standards to support shipboard power systems. The first success in this area was the publishing of IEEE 1662-2008, "IEEE Guide for the Design and Application of Power Electronics in Electric Power Systems on Ships". The second standard has completed balloting and is expected to be issued in 2010: IEEE P1709, "Recommended Practice for 1 to 35 kV Medium Voltage DC Power Systems on Ships." Updates to IEEE 45-2002, "Recommended Practice for Electric Installations on Shipboard" are currently being developed.

Within the Navy, an update to MIL-PRF-32272 to incorporate the NGIPS Power Conversion Modules is currently underway. Additionally, Design Data Sheet DDS-200-1 "Endurance Fuel Calculations" is also being updated. An update to DDS 310-1, "Electric System Load and Power Analysis for Surface Ships," to include provisions for zonal design and design for quality of service (both NGIPS concepts) is also planned.

Once these standards and updates are completed, their incorporation into the design process will be accomplished via the American Bureau of Shipping (ABS) Naval Vessel Rules.

In Spring 2010 work began on updating the NGIPS Technology Development Roadmap. An evaluation of the 2007 roadmap revealed:

- The technology descriptions are still good.
- Progress has been made in achieving the roadmap objectives.
  - The plan allowed for decentralized execution.
  - Industry, ONR, NAVSEA, and Academia have aligned much of their Power Systems R&D with the roadmap.
  - IEEE standards development has been very productive.
- Good and Bad with not including Execution Plan
  - Good: Stakeholder could agree on what needed to happen as long as they didn't have to commit to funding it.
  - Bad: Many tasks were not funded. NGIPS crosses multiple OPNAV sponsors, increasing the challenge to coordinate investments.
- Progress in implementing the Business Model has been slow.
- The focus on new design ships is not in alignment with current acquisition approach to relying on modified repeat designs.

The ongoing effort to update the NGIPS Technology Development Roadmap is directly addressing the following:

- Reflect evolution of the 30 year shipbuilding plan
- Incorporate Legacy Low Voltage Distribution systems
- Increase coverage of Hybrid Electric Drive
- Update tasks
- Refine the Business Model

To address the schedule and budget aspects of the tasks identified in the new roadmap, a separate program plan is being developed.

6.3.3 Evaluation of IPS and NGIPS

IPS and NGIPS can be evaluated against the criteria established by Doerry (2006) for institutionalizing a technology:

• **Demonstrate the Technology Early:** IPS has successfully accomplished this with test systems at NAVSSES Philadelphia.

• **Incorporate the basic technology into production units**: IPS equipment is currently being produced and tested for installation on DDG 1000. Production Power Node Control Centers (PNCCs) have been produced to meet the current requirements of MIL-PRF-32272. Modules adhering to NGIPS specifications have not been produced.

• **Establish a common architecture and interfaces**: IPS only partially addresses architecture. Although the early work on IPS stressed architecture, the systems for DDG 1000 were acquired as two sub-systems that did not conform to the original IPS architecture. The interfaces developed are specifically for DDG 1000 and not explicitly defined for multiple ship applications. NGIPS has broadly defined the architectures in the NGIPS Technology Development Roadmap. Power Interfaces for MVAC and AC-ZEDS are well defined in MIL-STD-1399. Control Interfaces and HFAC power interfaces are currently undefined. General interfaces for MVDC are described in IEEE 1709.

• **Establish a common design processes**: NGIPS through its shipyard team contracts are developing a NGIPS Conceptual Design Application Handbook and a NGIPS Conceptual Design ZEDS Application Handbook. A number of professional journal articles have described NGIPS design processes.

• **Incorporate the architecture and design processes into design tools**: The arrangement of large components is currently a part of ASSET. A ZEDS "wizard" is currently used to scale DDG-1000 components for use on other ship designs. More work is needed to translate Load Analysis data into ship system design solutions.

• **Codify the practice in Government or Industry specifications, standards and guides**. Efforts are currently underway to update MIL-PRF-32272 to produce a specification for the PCM-1A and PCM-2A modules. Quality of Service is incorporated in IEEE P1709 and will be incorporated in the future update to IEEE 45. An update to DDS-200-1 to define endurance fuel requirements is currently underway. These efforts only represent a small fraction of the specifications, standards, and guides needed to institutionalize NGIPS.

• **Teach the architecture and design process as part of a typical Engineering School Curriculum**. While some progress has been made in incorporating IPS and NGIPS into ship designs at schools teaching naval architecture, very little progress has been made in teaching IPS and NGIPS power system design at universities. A number of graduate students have worked on IPS and NGIPS related thesis topics (principally through the Electric Ship Research and Development Consortium), but a comprehensive IPS system design process has not been taught. A week long course on IPS design has been taught by NAVSEA for continuing education.

6.4 Set Based Design on Ship to Shore Connector

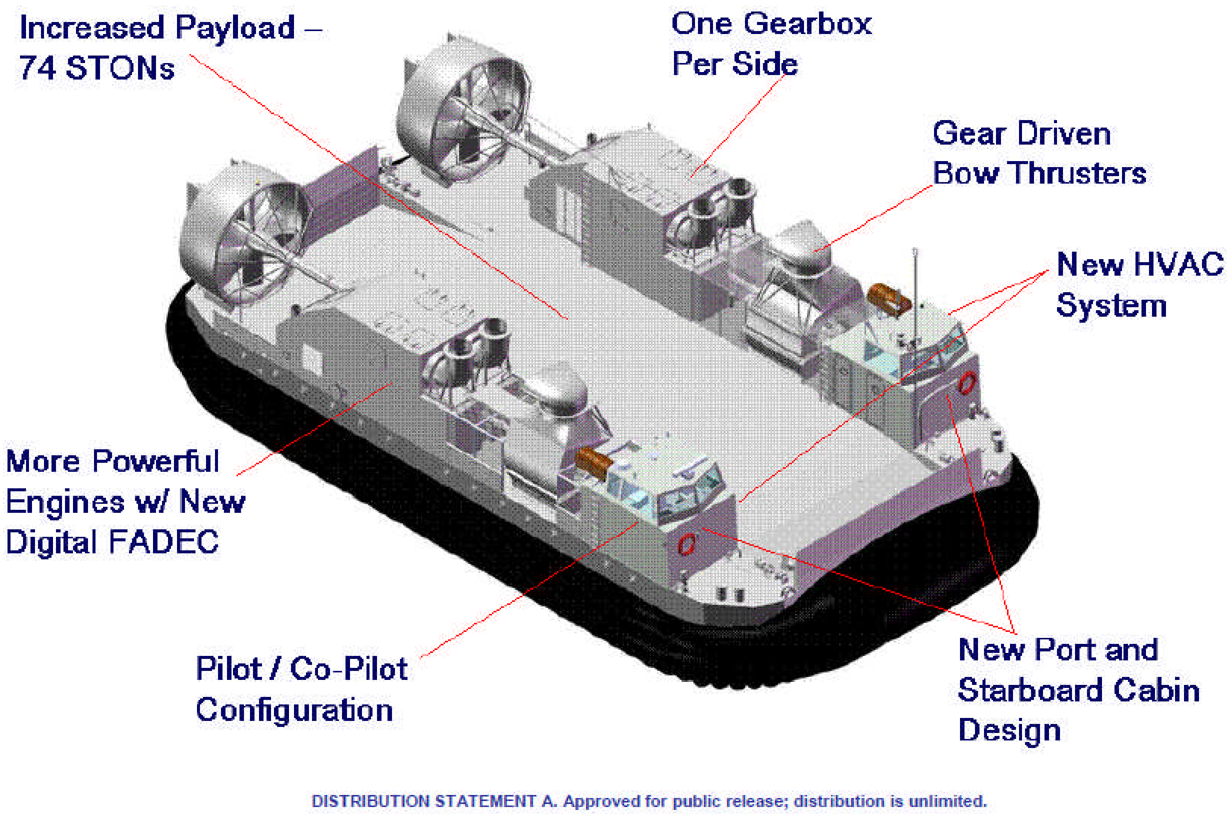

Figure 26: Ship to Shore Connector (Rivers 2009)

The introduction of the Set-Based Design (SBD) method to the ship design process is an excellent example of a technology transition of a process from academia to the practicing engineers in industry and the Government.

In 2006 NAVSEA and PMS 377 began studies to determine the characteristics of a replacement for the aging Landing Craft Air Cushion (LCAC). This new program, the Ship to Shore Connector (Figure 26) will deliver a new craft that will carry more, require less maintenance, and reduce crew workload as compared to the legacy LCAC. In 2007 planning began for the preliminary and contract design which was scheduled to start in 2008. It was soon realized that little progress had been made in the United States in air cushion vehicle design or production since the late 1970s when the original LCACs were designed. There had been no new designs within the U.S. since then. In fact many of the design software programs used for the LCAC design had been lost. The Navy realized it had to re-establish an air cushion vehicle design capability.

Prior to the SSC program, the Navy generally employed two design methods: Synthesis Model based Design Optimization and the Classic Design Spiral. In Synthesis Model Based Design Optimization, low fidelity parametric models are used to create hundreds or thousands of concepts to fully explore a design space. Based on the optimization method used, a single point is then chosen on which to iterate using the Classic Design Spiral. The difficulty with this approach is that the level of definition from the parametric models is usually not sufficient to guarantee convergence of a

design spiral method within the roughly one year typically allocated to Preliminary Design. Also, even if a converged design was found, the design spiral method was less likely to find an “optimum” solution. While the existing LCAC was obviously a converged design, it did not meet the requirements of the SSC. Howard Fireman, Director of SEA 05D (Surface Ship Design and Systems Engineering) was not convinced that evolving the LCAC design using the design spiral would result in a converged design that met the SSC requirements within the time allocated for Preliminary Design. As shown in Figure 27, Set Based Design would prove to be an effective bridge between Synthesis Model based Design Optimization and the Classic Design Spiral. (Singer et al. 2009)

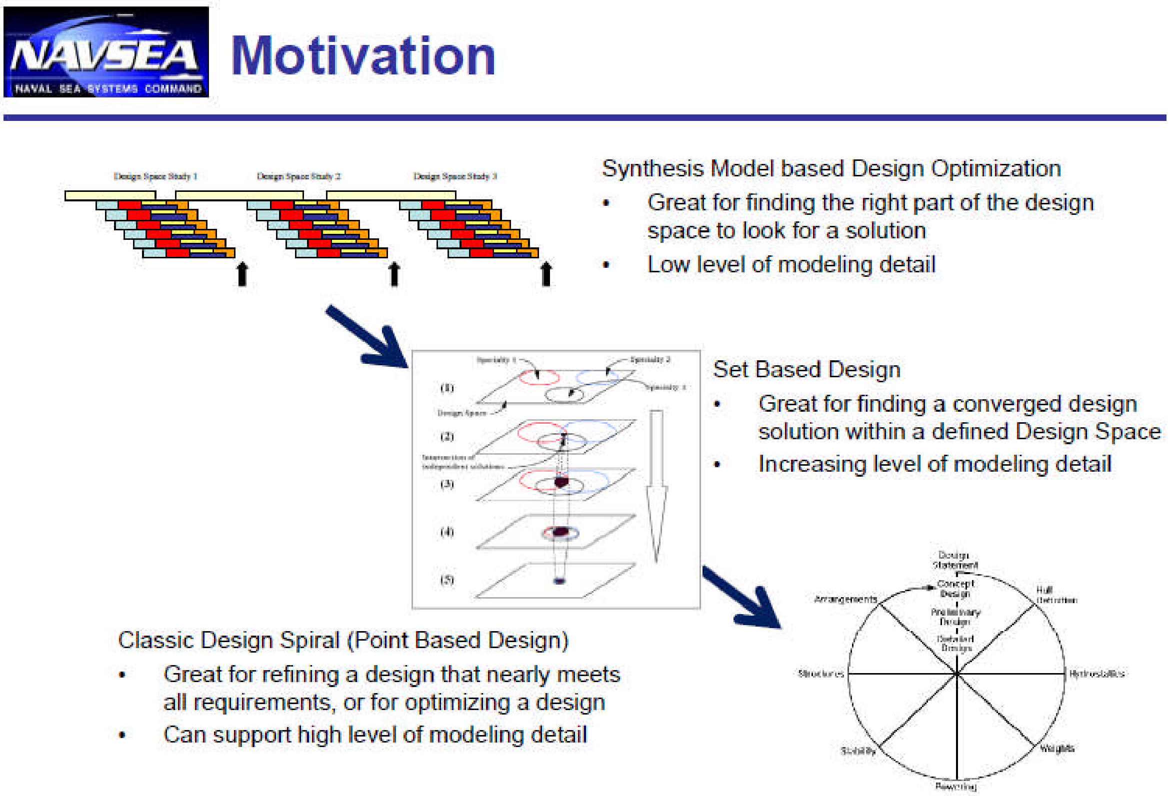

Figure 27: Set Based Design Motivation

Set Based Design is generally attributed to Toyota. As described by Singer et al. (2009):

> "The Toyota processes produce world-class designs in a significantly shorter time than other automobile manufacturers. The main features of this design process include:
>
> 1. broad sets of design parameters are defined to allow concurrent design to begin,
>
> 2. these sets are kept open longer than typical to more fully define tradeoff information[3],

[3] Design decisions are delayed in comparison to the Design Spiral method.

3. the sets are gradually narrowed until a more globally optimum solution is revealed and refined.

4. As the sets narrow, the level of detail (or design fidelity) increases"

The Toyota design methods were transitioned to the United States through the Japanese Technology Management Program sponsored by the Air Force Office of Scientific Research at the University of Michigan. Products of this work included:

Allen Ward, Jeffrey Liker, John Christiano and Durward Sobek II paper “The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster,” Sloan Management Review, 36:53-61 Spring 1995.

“Toyota, Concurrent Engineering, and Set-Based Design,’ Ch. 8 in Engineered in Japan: Japanese Technology Management Practices, New York, NY. Oxford University Press, pp. 192-216.

In 1998, Joshua Bernstein from MIT wrote a Master of Science Thesis “Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices” This thesis did an excellent job in describing Set Based Design and comparing it to other design methods.

Between 1998 and 2003, the University of Michigan Department of Naval Architecture and Marine Engineering completed a series of research projects that concluded SBD could be used to successfully design a ship. In 2003, David Singer earned a Ph.D. with his dissertation, “A Hybrid Agent Approach for Set-Based Conceptual Ship Design through the Use of a Fuzzy Logic Agent to Facilitate Communications and Negotiations.” Dr. David Singer would subsequently accept a position as Assistant Research Scientist at the University of Michigan in 2006. In 2007 Dr. Singer received the Young Investigator Program Award (YIP) from the Office of Naval Research. His proposal was based on his dissertation work on SBD. Through the YIP award, Howard Fireman learned of the potential for SBD.

Between October 30 and Nov 1, 2007 a preliminary design workshop was held at NSWC Carderock to support preliminary design planning of the SSC program (Then named the Joint Maritime Assault Connector -- JMAC). At the direction of Howard Fireman, Professor Singer briefed Set-Based Design. SBD was met with guarded enthusiasm at the workshop.

In the following months, the value of SBD was realized by the engineers in SEA 05D. On February 4, 2008, VADM Paul Sullivan (COMNAVSEA) signed a memo (authored by Steve Wynn and CAPT Norbert Doerry in SEA 05D) on "Ship Design and Analysis Tool Goals" that endorsed SBD as a valid design method. Specifically, the memo stated that “Synthesis tools must be compatible with Design of Experiments, Response Surface, and Set-Based Design Methodologies”

In February 2008, Set Based Design was incorporated into the SSC Engineering Management Plan. As shown in Figure 28 and Figure 29, it reflected a five month SBD effort followed by two design spirals. A series of trade-studies would systematically reduce the design space. Planning of the SBD phase was hampered by lack of experience in SBD by the Ship Design team. For example, tasking statements provided to participants were based on more traditional design spiral methods.

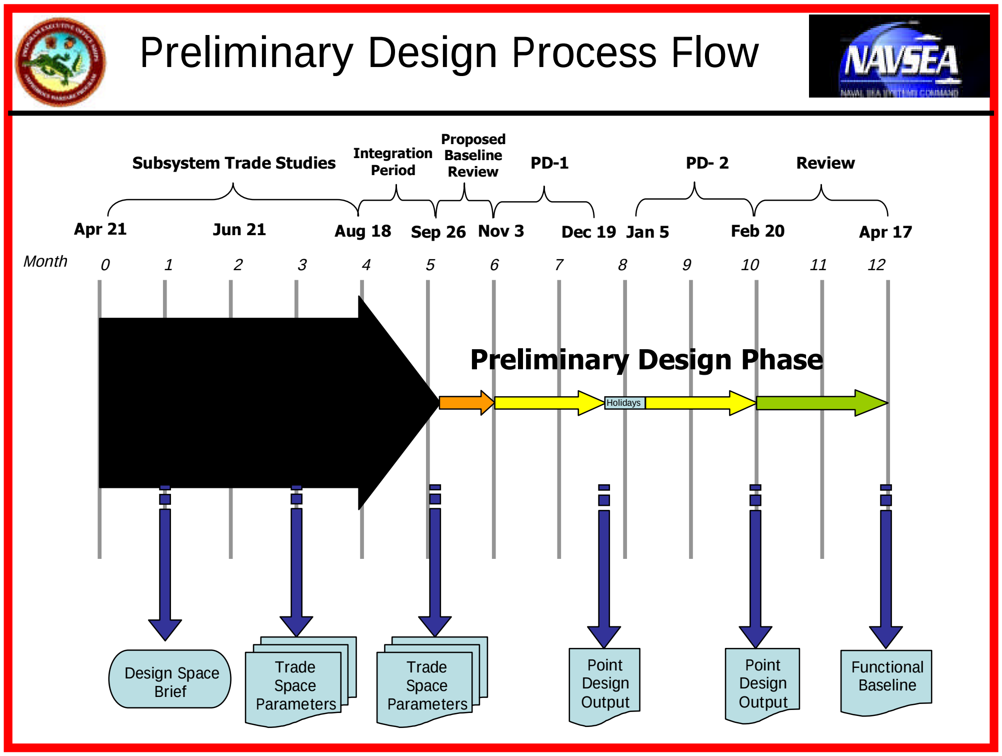

Figure 28: SSC Preliminary Design Process Flow

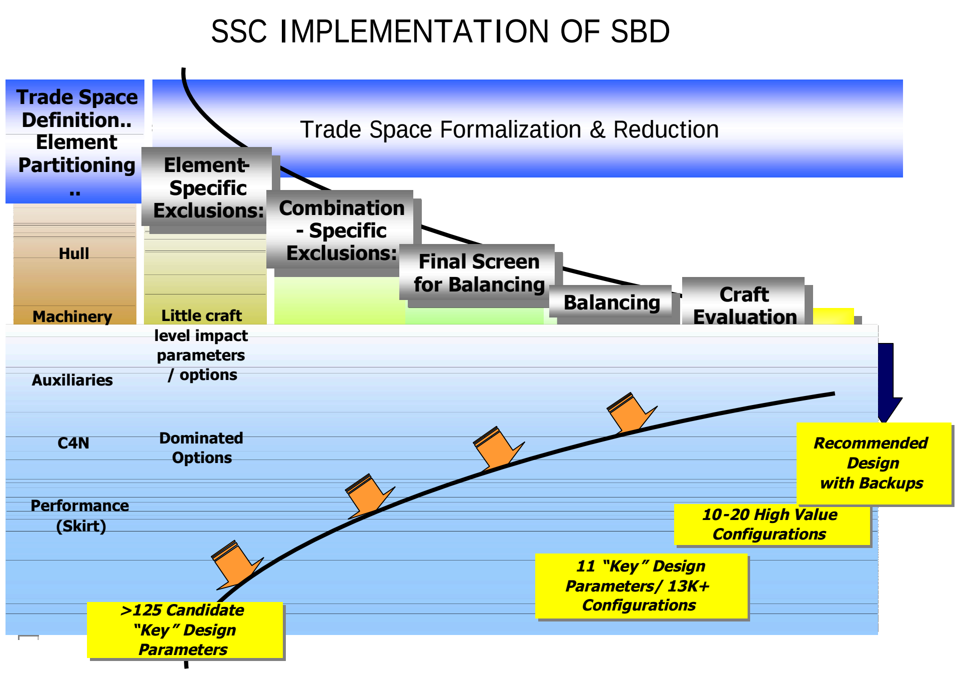

Figure 29: SSC Implementation of SBD

In March 2008 a SSC Preliminary Design Kick Off was held. In April 2008 the SSC program achieved Milestone A:

Professor Singer became a participant in the process to effectively transition the knowledge. He helped the SDM leadership team structure the studies and integrate the results. His expertise was critical in ensuring that the SBD method was successfully executed in an organizational structure that was not optimized for it. Particularly at the beginning of the process, not all team members were enthusiastic supporters of the method. By the end of the SBD in September 2008, most saw value in the method.

In September 2008 a SSC Baseline was selected -- marking the completion of SBD. During that same month, the SSC team briefed SBD lessons to the SEA 05D CG(X) Team. Until the CG(X) program was cancelled, SEA 05D planned to use SBD during its Preliminary Design. The SSC preliminary design would complete on schedule and less than 10% over the original budget.

On June 1, 2009 an updated version of the Ship Design Manager (SDM) Manual recommended Set Based Design as the preferred design method for Pre-Preliminary and the early stages of Preliminary design. The SDM Manual is the primary document guiding Ship Design Managers in planning design and engineering efforts for surface ship and aircraft carrier ship acquisition programs.

In the spring of 2010 Dr Singer and Dr Doerry briefed SBD to members of the Ohio Replacement (SSBN(X)) program as that program began its planning for preliminary design. It remains to be seen whether this program adopts SBD for its design process.

SBD can be evaluated against the criteria established by Doerry (2006) for institutionalizing a technology:

• **Demonstrate the Technology Early:** SBD was demonstrated by Toyota and later in the experiments at the University of Michigan.

• **Incorporate the basic technology into production units**: SBD was incorporated into the Preliminary Design of the Ship to Shore Connector.

• **Establish a common architecture and interfaces**: The basic method is described in the SDM Manual of June 2009.

• **Establish a common design processes**: The basic design process is described in the SDM Manual of June 2009. This process should be improved as more experience with SDM is gained.

• **Incorporate the architecture and design processes into design tools**: The COMNAVSEA memo of Feb 4, 2008 established support of SBD as a goal for tools development. The OSD CREATE program is currently developing tools that will facilitate SBD in the future.

• **Codify the practice in Government or Industry specifications, standards and guides**. The practice is included in the SDM Manual of June 2009. A more detailed guide or handbook is desirable.

• **Teach the architecture and design process as part of a typical Engineering School Curriculum**. SBD is being incorporated into the Naval Architecture and Ship Design curriculum at several universities. In several cases, only a basic introduction to the method is presented. Over time a more thorough presentation of the material is expected.

7. RECOMMENDATIONS

7.1 Promote Use of Product Lines and Associated Technology Development Roadmaps

The current model favoring transitioning technology directly from S&T to products directly supporting acquisition programs has lead to the R&D "Valley of Death." The principal cause of the "Valley of Death" is that a ship acquisition program has a very short window following Milestone A to fund technology development that will mature in time to support integration into the overall ship design process. Technology that is not perceived to be ready during this short window will typically not be incorporated. Unfortunately, without a ship acquisition program supporting the technology development, the technology many not receive sufficient support and funding to be ready for the next ship design opportunity as well.

Transitioning to a Product Line approach is more likely to result in technology being ready for product development when specific ship acquisition programs need them. In a product line approach, BA-4 programs partner with BA-3 S&T efforts to mitigate technical risks and build the industrial capability to produce a product meeting the ship acquisition needs quickly and affordably. While BA-3 efforts concentrate on achieving a TRL level 5, BA-4 Product Line programs concentrate on achieving an EMRL 3.

A significant advantage of using a Product Line Approach is that technologies are much more mature when incorporated into acquisition programs. As shown in Figure 30, employing Mature technologies has shown on average to significantly reduce RDT&E Cost Growth.

Technology Development Roadmaps are excellent tools for keeping the Resource Sponsor, Science and Technology Community, Acquisition & Engineering Community, and Industry working towards a common vision. The development and promulgation of this shared vision is an important element of transitioning knowledge among the communities.

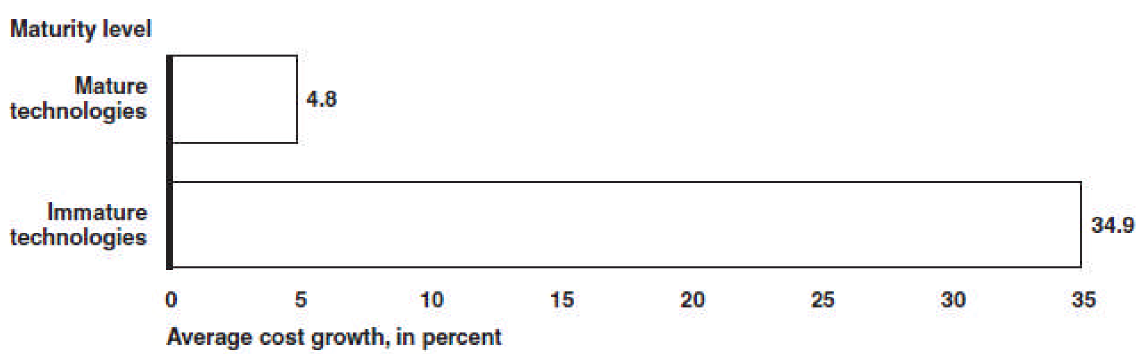

Figure 30: Average Program RDT&E Cost Growth from First Full Estimate (GAO 2006)

7.2 Employ More Robust Metrics

Currently, the Technology Readiness Level (TRL) is used as the predominate metric for evaluating technology. Unfortunately the TRL does not measure many attributes necessary for a successful technology transition. TRL is most appropriate for S&T and less appropriate for product development. Other metrics that can prove useful for different stages of technical maturity are:

7.2.1 Knowledge Creation

a. Technology Readiness Level (TRL)
b. Consistency with applicable Technology Development Roadmap
c. Progress against applicable Technology Transition Agreement(s)
d. Product Line receipt of knowledge
e. Product Line commitment for fiscal responsibility

7.2.2 Product Line Definition and Development

a. Applicability to customer needs
b. Manufacturing Readiness Level (MRL) (incorporates TRL)
c. Technical Performance Metrics
d. Affordability Performance Metrics
e. Progress against Specification, Standards, and Handbook development plan.
f. Development Funding Assessment
g. Risk Assessment

7.2.3 Product Development and Ship Integration

a. Development and quality of Design Integration information
b. Cost, Schedule, and Technical Performance assessment
c. Risk Assessment
d. Quality Assurance
e. ILS performance
f. Operability assessments (user feedback)

7.2.4 Production

a. Cost, Schedule, and Technical Performance assessment
b. Quality Assurance
c. Risk Assessment to include
    a. Obsolescence Management
    b. Diminishing Sources
    c. Regulatory Changes

d. Operability assessments (user feedback)

d. Reliability, Availability, and Maintainability assessment

e. Technology Insertion Assessment

7.3 Improve Technology Transition Agreements

Technology Transition Agreements are commonly used as a tool for technology transition between BA-3 and BA-4 programs. While there is not a single standard format for Technology Transition Agreements, many of the available templates have the following weaknesses:

a. A perspective that technology transition occurs at the end of BA-3 instead of as a partnership between the BA-3 and BA-4 Programs. The TTA concentrates on what the BA-3 program will have accomplished at its conclusion. Very little is included with respect to how the BA-4 activity will prepare its programs (i.e. architectural modifications) to accept the new technology.

b. The discussions on risk typically are with respect to the successful execution of the BA-3 program. Ideally, the Technology Transition Agreements should also highlight how the BA-3 program mitigates risk in the BA-4 program.

c. The TTA concentrates on the BA-4 activity making a funding commitment to further fund technology development if the BA-3 program meets its commitments. In reality, the funding commitment is generally weak and unenforceable.

d. Very little is incorporated to discuss how knowledge created in the BA-3 program is shared with the participants in the BA-4 program.

e. Very little is incorporated to discuss how product evolution and knowledge gained in the BA-4 program should be communicated back to the BA-3 program. This is especially true if new risks are identified during the BA-4 program or if existing risks are mitigated in the BA-4 program and no longer require mitigation in the BA-3 program.

f. The management of Intellectual Property Rights is not generally described to a useful level of detail.

Addressing these weaknesses is recommended for future Technology Transition Agreements.

7.4 Fully Implement Relationship Managers

Within the Navy, there are a number of individuals that assist the technology transition process. Many of these individuals fulfill some or most of the roles of a Relationship Manager. Relationship Managers in the S&T Community and the Acquisition and Engineering Community would frequently communicate with the program officer and technical authority communities to inform the program officer of technologies that the technical authorities need and want, and to inform the technical authorities of new technologies as they emerge and mature.

The GAO (2006) has recognized the effective use of Relationship Managers as an Industry Best Practice.

The Relationship Managers should play an important role in the development and maintenance of Technology Development Roadmaps. They should also help both the S&T and Acquisition and

Engineering Communities evaluate the alignment of projects to the roadmaps. The Relationship Managers could also be invaluable in developing good Technology Transition Agreements.

Ideally, a handbook should be developed to describe the expected roles and responsibilities of a Relationship Manager. This handbook should be frequently updated to capture the lessons learned by the Navy's Relationship Managers.

7.5 Modify DODFMR to include Technology Transition Activities in BA3

The DOD Financial Management Regulation currently defines BA-3 as:

> "Budget Activity 3, Advanced Technology Development (ATD). This budget activity includes development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. ATD includes concept and technology demonstration of components and subsystems or system models. The models may be form, fit and function prototypes or scaled models that serve the same demonstration purpose. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use. Projects in this category have a direct relevance to identified military needs. Advanced Technology Development demonstrates the general military utility or cost reduction potential of technology when applied to different types of military equipment or techniques. Program elements in this category involve pre-Milestone B efforts, such as system concept demonstration, joint and Service-specific experiments or Technology Demonstrations and generally have Technology Readiness Levels of 4, 5, or 6. Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of Science and Technology (S&T) and into the acquisition process within the future years defense program (FYDP). Upon successful completion of projects that have military utility, the technology should be available for transition."

Note that while the definition states that "technology should be available for transition," the definition does not directly incorporate technology transition activities. This implies technology is "thrown over the wall" to the receiving BA4 programs. Alternately, the definition could include the following language to facilitate better ongoing dialogue and partnering between the S&T Community and Industry / the Acquisition and Engineering Community:

> "Projects in this category incorporate Technology Transition coordination efforts with related BA 4 programs to ensure relevant technology risks are mitigated and that applicable knowledge is transitioned to appropriate organizations supporting related BA4 activities."

This proposed change would enable a clearer implementation of the Defense Authorization Act, 2001 which requires ONR to "…manage the Navy's basic, applied, and advanced research to foster transition from science and technology to higher levels of research, development, test, and evaluation."

An alternate approach would be to give the System Commands BA-1 through BA-4 budget authority to develop product lines.

7.6 Modify DODFMR to split BA4 into Product Line Development and Advanced Component Development and Prototypes.

Currently, Product Line Development and Product Development are both funded under BA4. A downside to this approach is that the underfunding of Product Line Development has been masked

for the past 15 years by ship specific product development. The recent awareness of the lack of commonality across recent ship acquisitions is a symptom of this practice.

An alternate approach would be to create a new Budget Activity (BA-8?) to fund cross platform product line development. By splitting out Product Line Development from Product Development, maintaining a funding balance is easier visualized and maintained.

7.7 Assign OPNAV N091 as the resource sponsor for Product Line Development in addition to S&T.

One of the challenges today is that in the transition from 6.3 to 6.4 funding, transitions are typically required by the creator / user of knowledge (Science and Technology vs Industry), by the Fiscal Management of the programs (ONR vs Acquisition and Engineering Community) and by the Resource Sponsor (N091 vs the platform resources sponsors). A failure in any one of these transitions can result in a Technology Transition failure.

The GAO (2006) reported that one significant difference between leading companies and the Department of Defense is that the accountability for Management and Funding of Technology transition was the responsibility of the Lab, while in DOD it is typically the responsibility of the Engineering and Acquisition Community (Figure 31).

A different model for the Navy that is more closely aligned with the industry practice would be for the S&T Sponsor, OPNAV N091 to also be the sponsor for cross-platform Product Line Development. Management of the Product Line Development would either reside in the Systems Commands (such as NAVSEA) or within the PEOs (such as PEO-IWS).

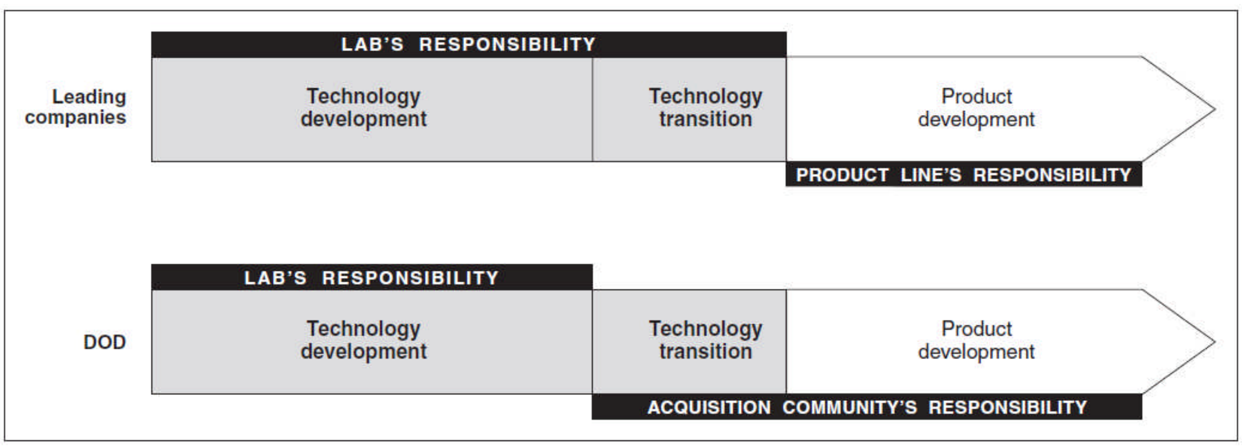

Figure 31: Accountability for Management and Funding of Technology (GAO 2006)

8. CONCLUSIONS

This paper has described how the S&T Community, the Resource Sponsors in the Office of the Chief of Naval Operations (OPNAV), the Acquisition and Engineering Community, Industry, and the Fleet work together to develop and transition technology from the academic and industrial research environment to installation on ships: The This paper presented both the current model and an alternate model for technology transition. These models reflect three drivers for inserting a new technology into a given system: filling a military capability gap, exploiting technology opportunities, and managing risk across a portfolio of systems. Several completed technology transitions as well as several ongoing transitions are examined using the traditional and alternate Technology Transition Models:

- Advanced Enclosed Mast / System (AEM/S) on LPD 17
- Hybrid Electric Drive (HED) on LHD 8
- Integrated Power System (IPS) on DDG 1000 and Next Generation Integrated Power System (NGIPS)
- Set Based Design (SBD) on the Ship to Shore Connector (SSC)

Based on the lessons learned from these examples the following recommendations to improve technology transition were discussed:

- Promote the use of Product Lines and Associated Technology Development Roadmaps
- Employ more Robust Metrics
- Improve Technology Transition Agreements
- Fully Implement Relationship Managers
- Modify the DOD Financial Management Regulation (DODFMR) to include Technology Transition Activities in BA-3.
- Modify DODFMR to split BA4 into Product Line Development and Advanced Component Development and Prototypes
- Assign OPNAV N091 as the resource sponsor for Product Line Development in addition to S&T.

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